1963

Summary report to Committee 10 of RCRBSJ, December 1963

Fritz Lab

LEHIGH UNIVERSITY INSTITUTE OF RESEARCH

LARGE BOLTED JOINTS

SUMMARY REPORT TO COMMITTEE 10
OF THE RESEARCH COUNCIL ON
RIVETED AND BOLTED
STRUCTURAL JOINTS

by

Project Staff: L. S. Beedle, R. J. Christopher
J. W. Fisher, G. H. Sterling
J. J. Wallaert

Fritz Engineering Laboratory Report No. 288.14

W

LARGE BOLTED JOINTS

SUMMARY REPORT TO COMMITTEE 10
OF THE RESEARCH COUNCIL ON
RIVETED AND BOLTED
STRUCTURAL JOINTS

by

Project Staff

(Not for Publication)

This work has been carried out as part of the Large Bolted Joints Project sponsored financially by the Pennsylvania Department of Highways, the Department of Commerce - Bureau of Public Roads, and the American Institute of Steel Construction. Technical guidance is provided by the Research Council on Riveted and Bolted Structural Joints.

Project Staff: L. S. Beedle, R. J. Christopher
J. W. Fisher, G. H. Sterling,
J. J. Wallaert

December, 1963

Fritz Engineering Laboratory Report No. 288.14

LARGE BOLTED JOINTS, PROJECT 288, LEHIGH UNIVERSITY

SUMMARY OF WORK COMPLETED OR IN PROGRESS

December, 1963

Council Spec: Why did we hold off?

Phase and Topic	Remarks	Tests Performed	Tests to be Completed	Available Material On Hand	Reports
I Compact Joints of A440 Steel and A325 Bolts Series E	Authorization: Committee 10 Minutes 4/19/60; 1/19/61 Completed	6 Joints E41a, E41b, E41c, E41e, E41f+, E41g++ + One wahser ++ No washers	None	55 - 7/8" x 5-1/4" 8A Lot Bolts	288.4 (IABSE) 288.7
II Long Joints of A440 Steel and A325 Bolts Variable Width Series E	Authorization: Committee 10 Minutes 4/19/60; 1/19/61 Completed	8 Joints E41, E46, E71, E74, E741, E101, E131, E161 One washer	None	Plate for 15 to 20 joints at B. S. Co. 115 - 8B Lot 7/8" x 5-1/2" 150 - H Lot 7/8" x 9-1/2"	288.4 (IABSE) 288.7
III Inspection of Bolts Tightened by the Turn-of-Nut Method Series E	Authorization: Committee 9 Minutes: 1/30/60 Committee 10 Minutes: 1/30/62 Dormant	Torque Measurements with a Hand Torque Wrench on Bolts of Phase II	Tests to Determine the "Breakaway" and Kinetic Torque		288.1 288.2
IV a) Calibration of A325 Bolts Series E, F	Authorization: Committee 10 Minutes: 1/30/62 Committee 10 Minutes: 11/7/62 Active	Direct and Torqued Tension Tests of 170 - A325 Bolts	F Series Bolts 1-1/8" dia.	50 - D Lot 140 - H Lot 50 - 8A Lot 100 - 8B Lot	271.21 (ASCE) 288.5
b) Calibration of A354 BC and A490 Bolts Series J, K	Authorization: Committee 10 Minutes: 1/30/62 Committee 10 Minutes: 11/7/62 Active	Direct and Torqued Tension Tests of 7/8" and 1" dia. Bolts	None	4 Lots of A354 BC Bolts 13 Lots of A490 Bolts	288.9

Corr T. Cochrane in adv.

LARGE BOLTED JOINTS, PROJECT 288, LEHIGH UNIVERSITY

SUMMARY OF WORK COMPLETED OR IN PROGRESS

December, 1963

Phase and Topic	Remarks	Tests Performed	Tests to be Completed	Available Material On Hand	Reports
V Shear Tests of A354 BC and A490 Bolts in A440 and Constructional Alloy Steel Jigs Series J, K	Authorization: Committee 10 Minutes: 11/7/62 Active	Compression Shear: 15-A440 Jigs 12-C.A. Jigs Tension Shear: 15-A440 Jigs	Tension Shear: 12-C.A. Steel Jigs	Additional A440 and C.A. Steel	
VI Joints of Constructional Alloy Steel connected with A325 Bolts Series F	Authorization: Committee 10 Minutes: 11/7/62 Active	None	6 Joints: F42a, F42b, F42c, F42d, F42e, F42f, Long Joints to be specified	One lot of 1-1/8" dia. bolts. Plate material	
VII Joints of Constructional Alloy Steel Connected with A490 Bolts Series J	Authorization: Committee 10 Minutes: 11/7/62 Active	None	4 Joints: J42a, J42b, J42c, J42d, Long Joints to be specified	One lot of 1" dia. bolts. Plate material	
VIII Joints of A440 Steel Connected with A490 Bolts Series K	Authorization: Committee 10 Minutes: 11/7/63 Active	None	4 Joints: K42a, K42b, K42c, K42d Long Joints to be specified	KK lot of 7/8" dia. bolts. Additional A440 plate at B.S. Co.	
IX Cooperative Study with the University of Illinois	Authorization: Committee 15 Minutes: 2/14/63 Committee 10 RCRBSJ Meeting. Active	50 tests of 7/8" x 5-1/2" and 7/8" x 9-1/2" A490 bolts in the S.W. and solid plate	None	Various lots of 7/8" dia. bolts	

PROJECT 288

Phases Now Completed

Series E — Static tests of compact, long and wide A440 steel joints fastened with A325 bolts.

Phases Now Active

Series F — Static tests of joints made of constructional alloy steel fastened with 1-1/8" dia. A325 bolts.

Series J — Static tests of joints made of constructional alloy steel fastened with 1" dia. A490 bolts.

Series K — Static tests of joints made of A440 steel fastened with 7/8" dia. A490 bolts.

Phases Not Initiated

Series C — Static tests of shingle joints fastened with A325 bolts.

Series H — Static tests of high strength steel joints fastened with high strength rivets.

Series I — A study of hydrid connections in which two or more different grades of steel members are fastened.

Series S — Tests of large diameter bolts.

Phases Not Yet Formulated

a) Effect of punched holes.

b) Tightness and coefficient of friction as influenced by broom joints.

c) Fatigue of large joints.

PROJECT 288

SUMMARY OF REPORTS - TO DECEMBER 1963

Cap titles

Fritz Lab Report	
* 288.1	J. W. Fisher, S. E. Dlugosz, P. O. Ramseier "Summary Report to Committees 9 and 10" January 1962
* 288.2	J. W. Fisher, S. E. Dlugosz, P. O. Ramseier "Summary Reports for RCRBSJ" March 1962
288.3	"Large Bolted Joints Project 288 - Manual" (Contains the "File System, Summary and Phases, Test Preparation and Procedure, Standard Data Forms and Standard Project Forms" of Project 288)
288.4	P. O. Ramseier, J. W. Fisher L.S.B. "Static Tension Tests of A440 Steel Joints Connected with A325 Bolts" (Reports on tests of six pilot tests, five long and three wide joints fabricated of A440 steel at the tension-shear ratio of 1/1.0. To be published, Publication of the I.A.B.S.E., Vol. 23, 1963).
* 288.5	J. L. Rumpf, J. W. Fisher "Calibration and Installation of A325 Bolts" December 1962 (Revision of Report 271.11 plus additional studies on the heavy head A325 bolt in conjunction with the tests of large joints. To be published, Proceedings, A.S.C.E. St6, Vol. 89, 1963)
* 288.6	Project Staff "Summary Report to Committees 9 and 10" November 1962
* 288.7	J. W. Fisher, L. S. Beedle "Criteria for Designing Bolted Joints (Bearing-Type)" February 1963
* 288.8	J. W. Fisher, R. J. Christopher, J. J. Wallaert "Summary Report for RCRBSJ" March, 1963
* 288.9	R. J. Christopher, J. W. Fisher "Calibration of A354 Bolts" (Preliminary Report) March, 1963 (This report contains the results of direct tension and torqued tension tests on 7/8" and 1" diameter A354 bolts)

288.10 J. W. Fisher
"The Analysis of Bolted Plate Splices"
(In preparation)

288.11 R. J. Christopher
"Calibration of Alloy Steel Bolts"
(In preparation)

288.12 J. J. Wallaert
"The Shear Strength of A325 and Alloy Steel Structural Bolts"
(In preparation)

288.13 J. J. Wallaert
"The History of Internal Tension in Bolts Connecting Large Joints"
(In preparation)

* 288.14 Project Staff
"Summary Report to Committee 10 of RCRBSJ"
December, 1963

* Indicates distribution to subgroup, Pennsylvania Department of Highways, Bureau of Public Roads and certain other interested parties.

ANALYSIS OF BOLTED PLATE SPLICES

INTRODUCTION

A theoretical solution for the unequal distribution of load among the mechanical fasteners of bolted double-lap tension splices which act in a non-linear manner is summarized hereafter. To accomplish this solution, mathematical models have been developed which establish the relationship between deformation and load throughout the elastic and inelastic regions for the component parts of the connection.

ANALYTICAL MODELS

For the plate material the following stress-strain relationship was developed for the inelastic region:

$$\sigma = \sigma_y + (\sigma_u - \sigma_y)\left[1 - \exp.\left\{-\ (\sigma_u - \sigma_y)\ \left(\frac{g}{g-d}\right)\ \frac{e}{p}\right\}\right]^{3/2} \qquad (1)$$

where σ_y = static yield stress

σ_u = ultimate strength

g = gage

p = pitch

$e = \epsilon p$ = deformation

ϵ = strain in plate with a hole = $\frac{e}{p}$

$\sigma_y \leq \sigma \leq \sigma_{ult}$

Below the elastic limit, Hooke's law holds.

The theoretical curves are compared with the test data in Figs. 1 and 2. In Fig. 1 the comparison is made for both A7 and A440 steel. Figure 2 shows a comparison of the gage load versus deformation for A440 steel. The gage is varied from 3.32 to 5.74 in.

The analytical expression used to express the load-deformation relationship of a bolt in double shear was taken as:

$$R = R_{ult} \left(1 - \exp.(-\mu\Delta)\right)^{\lambda} \quad (2)$$

where R_{ult} = ultimate shear strength

Δ = deformation of bolt and bearing deformation of the connected material

μ, λ = coefficients which are functions of the type of connected material and type of bolt

Equation 2 is compared with the test data in Fig. 3.

The work of Francis and Rumpf has shown that the following compatibility conditions and equilibrium condition must be satisfied:

$$\Delta_i + e^{1}_{i,i+1} = \Delta_{i+1} + e^{m}_{i,i+1} \quad (3)$$

$$P_G - \sum_{i=1}^{n} R_i = 0 \quad (4)$$

Equations 1 and 2 are used with the equilibrium and compatibility conditions to accomplish the joint solution.

COMPARISON OF THEORY AND TEST

The theoretical solution has been compared with test results of eight full-size connections using 7/8-inch A325 bolts and A7 steel plate and seven full-size connections using 7/8-inch A325 bolts and A440 steel plate.

The comparison between the theory and experimental results is made in Fig. 4 for A440 steel joints. Three different comparisons are made. In one, the theoretical strength based on actual measured bolt and plate properties is compared with the test data. The other two comparisons indicate the influence that minimum strength materials have on the ultimate strength. The maximum deviation between the theoretical solution and the test results was 4%.

The solution has been used to make a number of hypothetical studies in order to ascertain the relative importance of a number of parameters on the ultimate strength of the connections. Among the variables studied were joint length, pitch, variation in fastener diameter, and variation in the relative proportions of the bolt shear and net tensile areas. These studies were made for both A7 and A440 steel plate connected with A325 bolts.

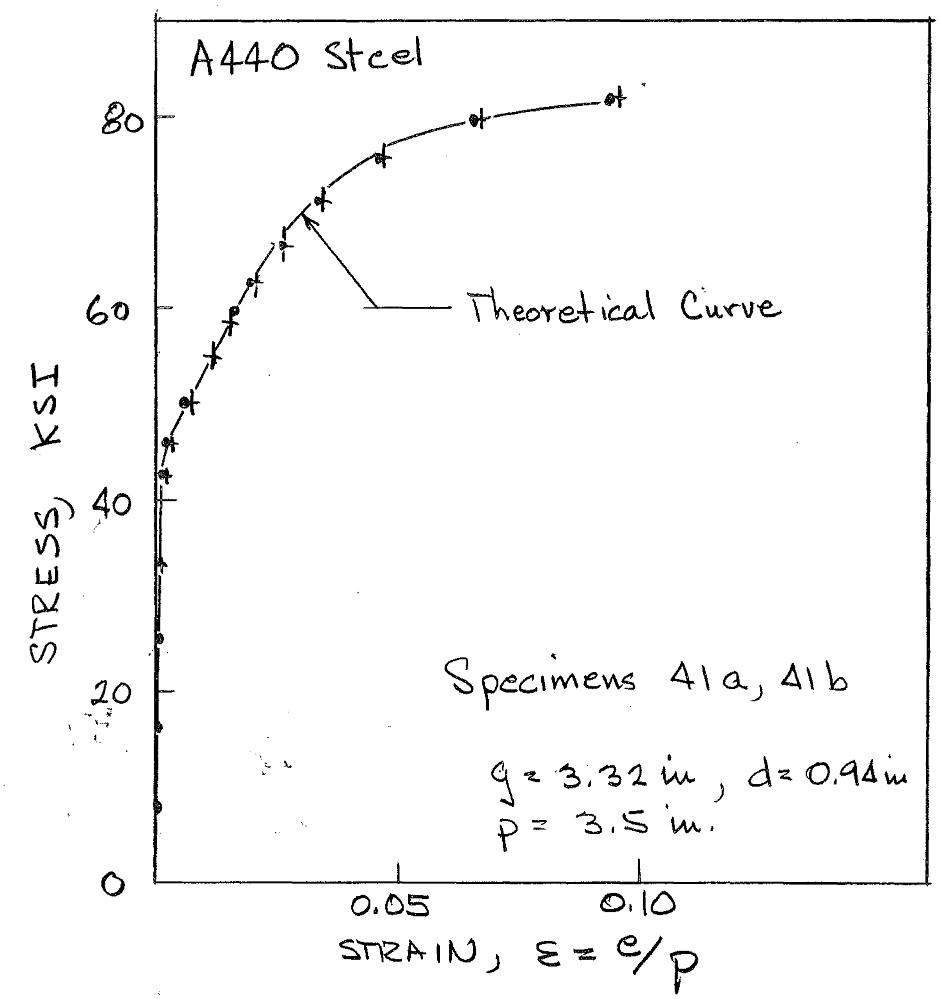
Figure 5 shows the effect of fastener diameter on the ultimate shear strength. The comparison is made for A7 steel and the pitch was maintained constant at 3.5 inches. Fastener diameter was found to have no significant effect on the average shear strength.

Figure 6 shows the effect of fastener pitch on the ultimate shear strength. As can be seen the fastener pitch had no appreciable effect on the shear strength other than its interaction with joint length. The total joint length, and not the number of fasteners (governed by pitch), was the most important variable insofar as the average shear strength was concerned.

Figure 7 summarizes the study of the variation in the relative proportions of the bolt shear and the net tensile areas. The comparison is shown for A7 steel plate connected by A325 bolts. This study shows that the "balanced design" concept has no meaning. A joint can only be in balance for a specified length which corresponds to a specific ratio of the bolt shear and the net tension area.

Effect of thickness

May not have checked linearity cond. as hole dia became markedly different from t.



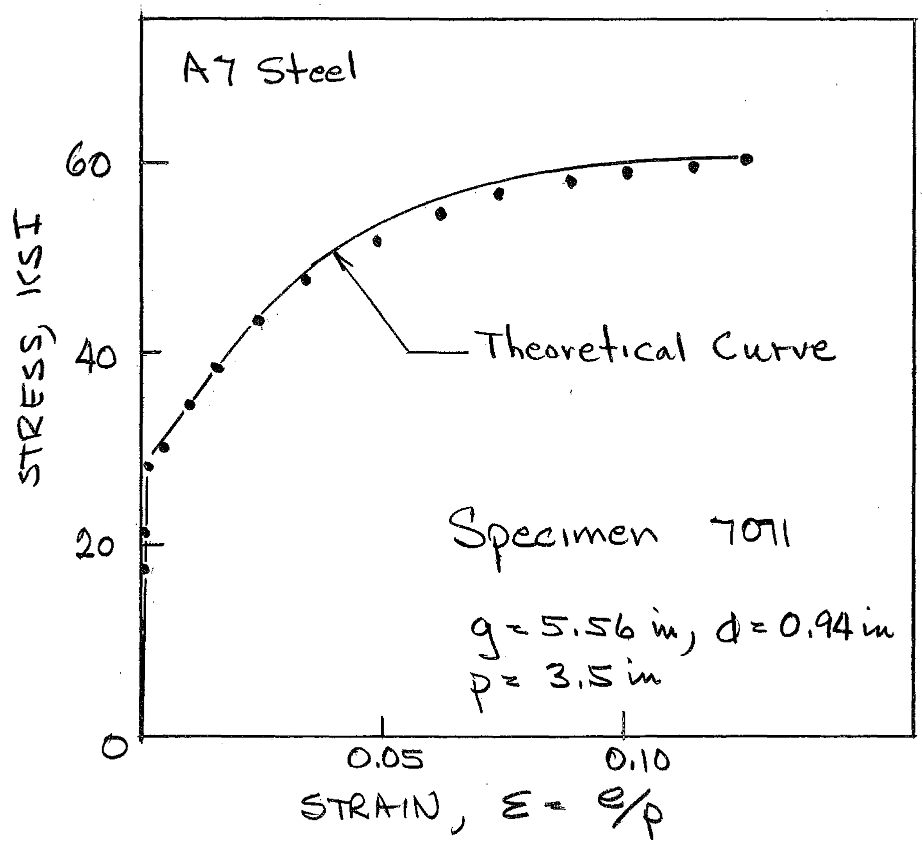


Fig. 1 Comparison of Theory with Test Data

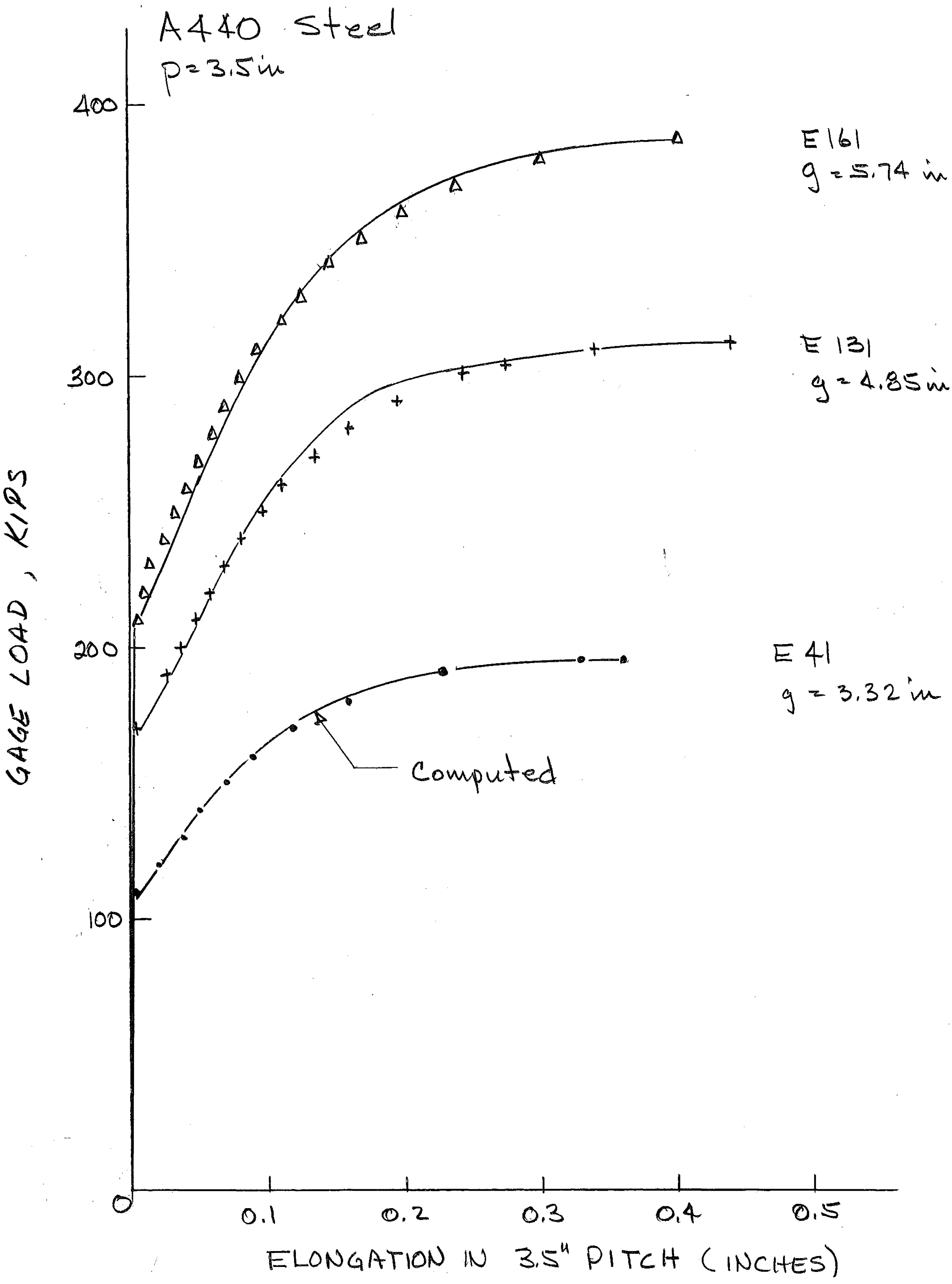
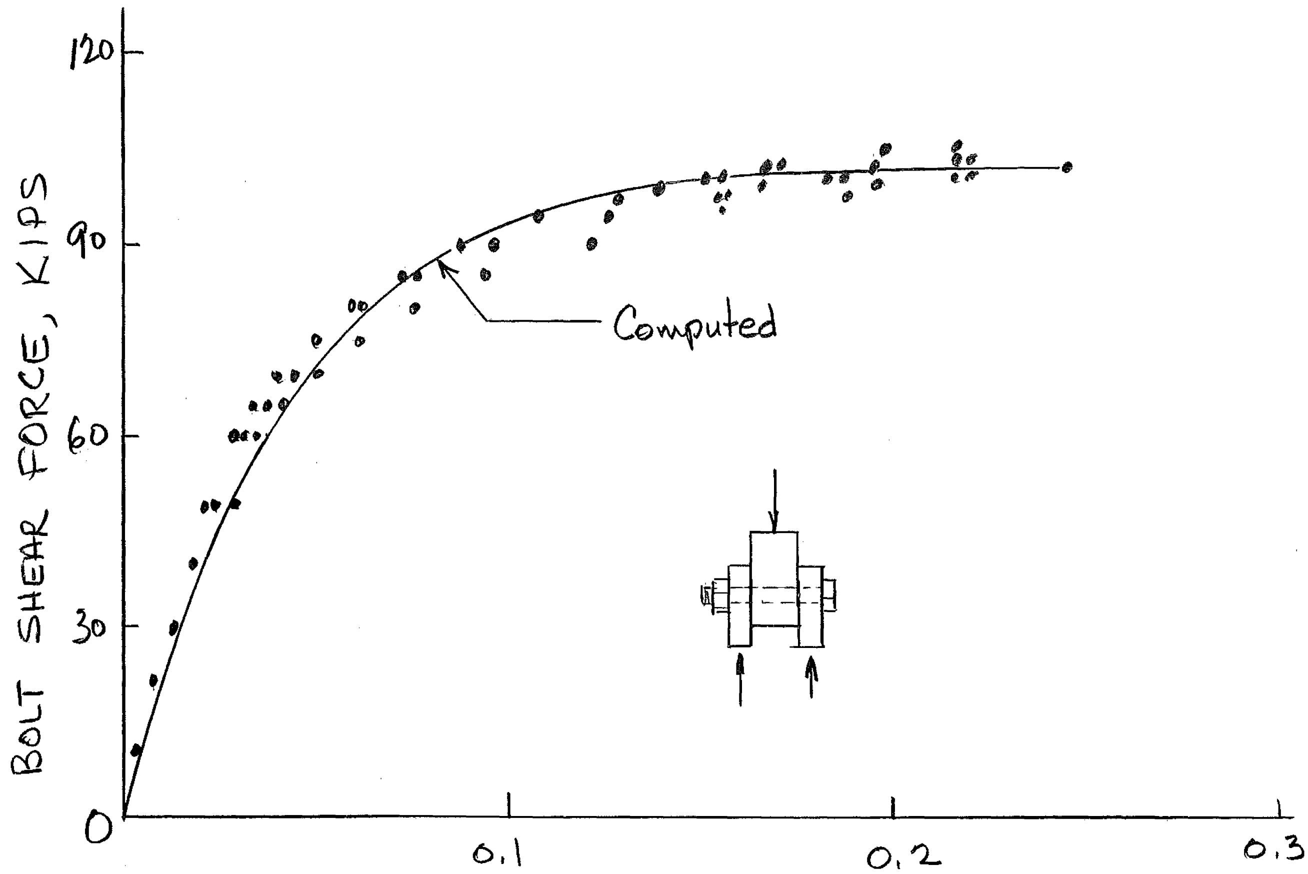


Fig. 2 Comparison of Computed Load-Deformation Characteristics with Plates having various Gage Widths



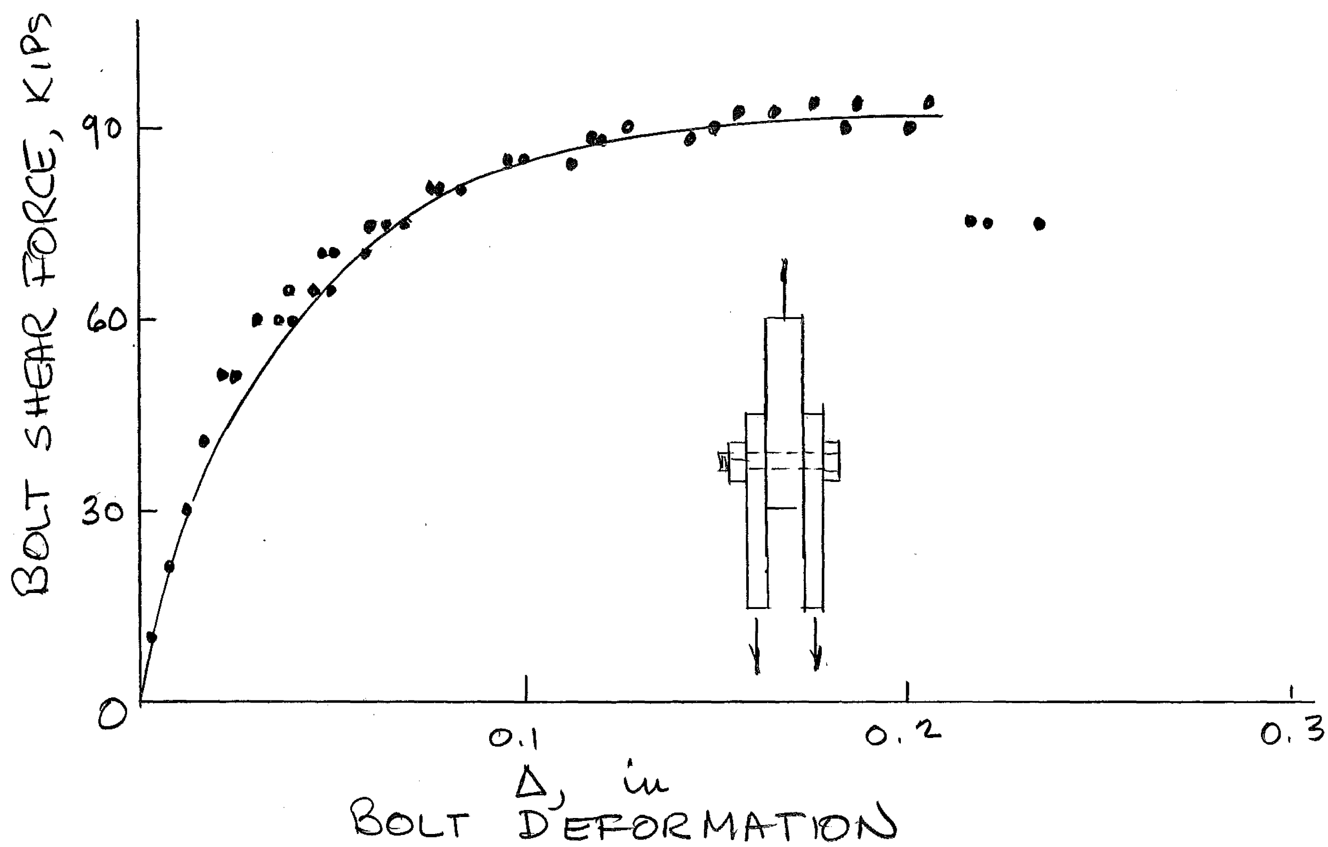
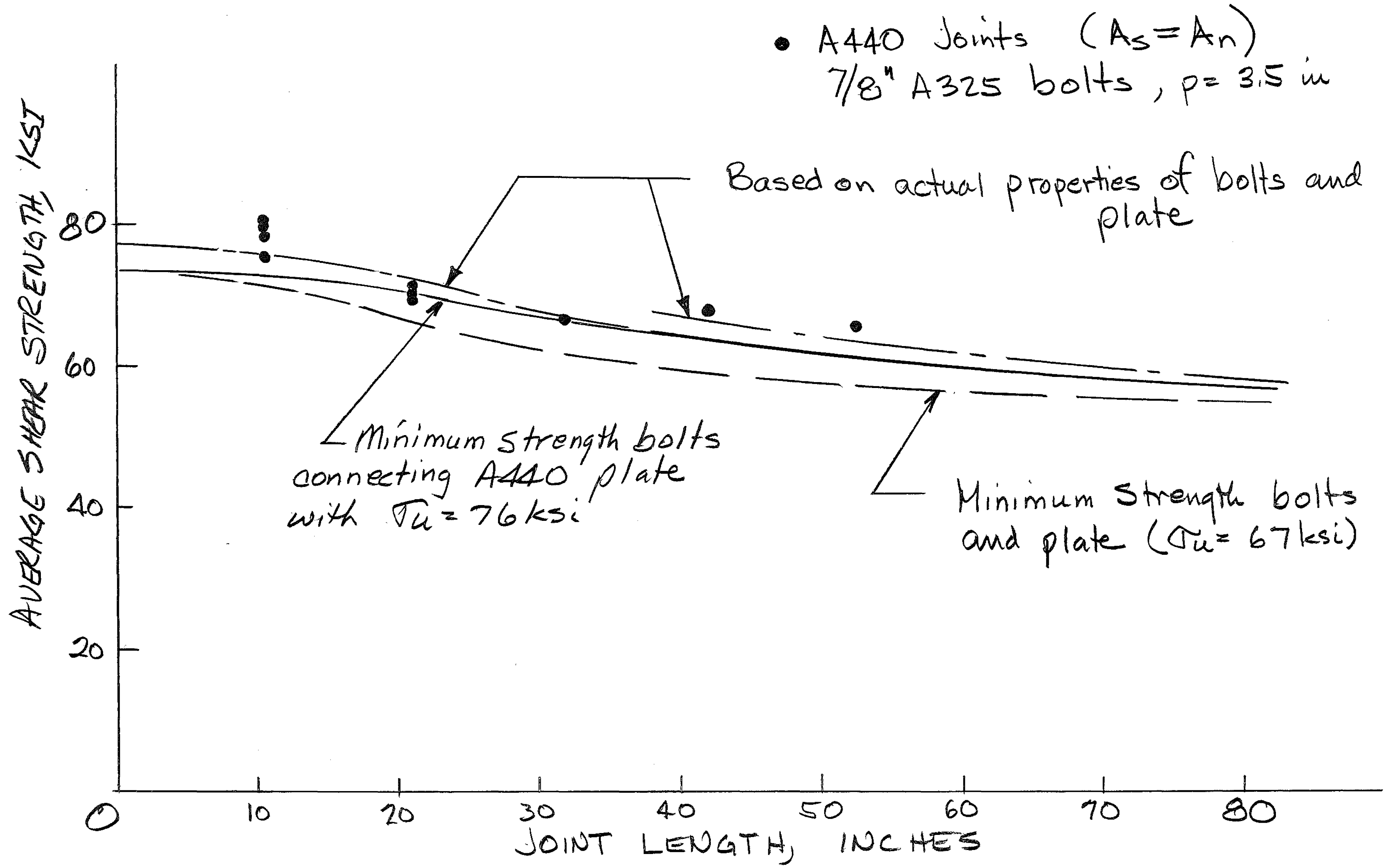


Fig. 3 Load-Deformation Characteristics of A325 Bolts



"I"

Fig. 4 Comparison of Predicted Ultimate Strength and Experimental Results

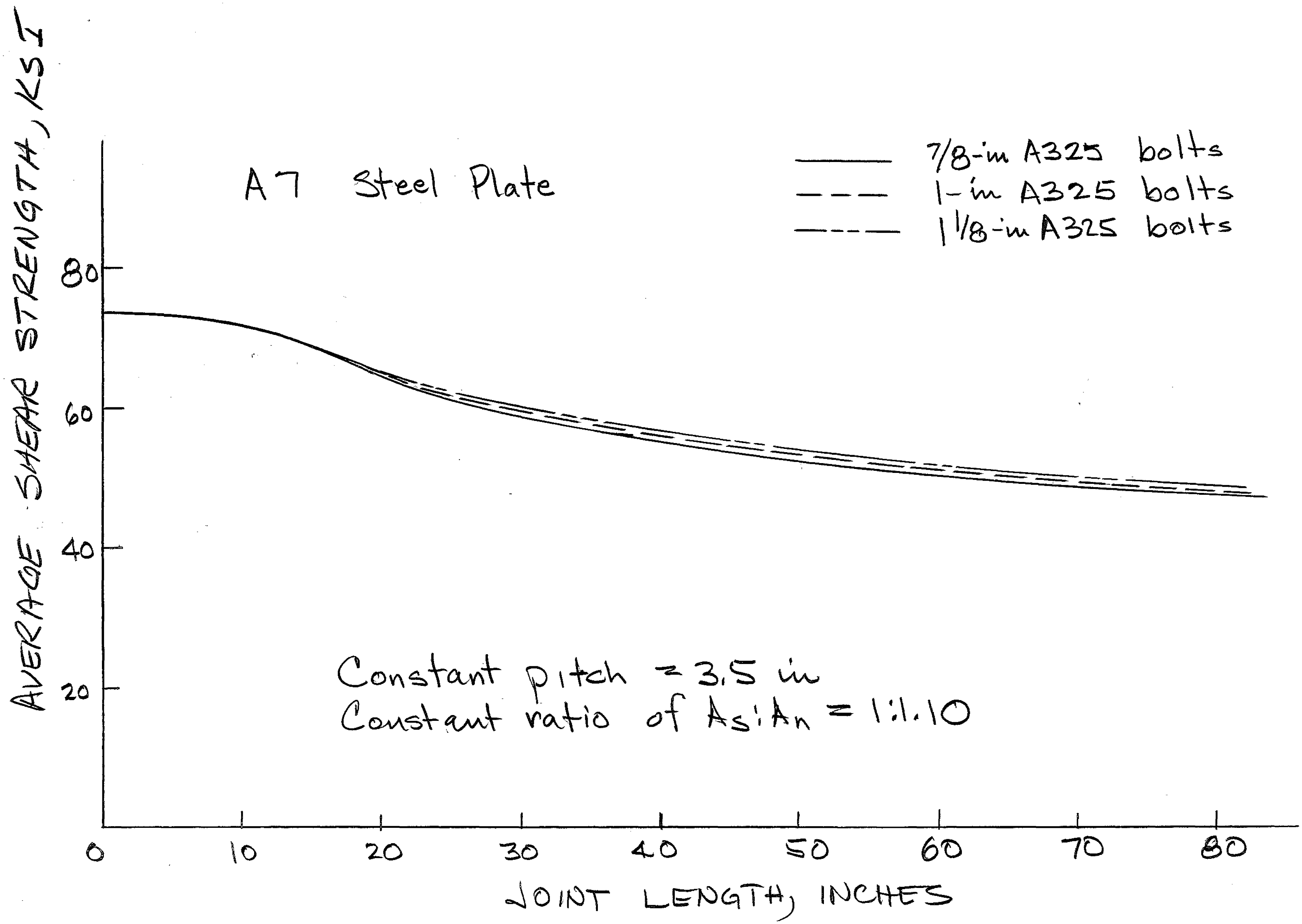


Fig. 5 Effect of Fastener Diameter on Ultimate Strength

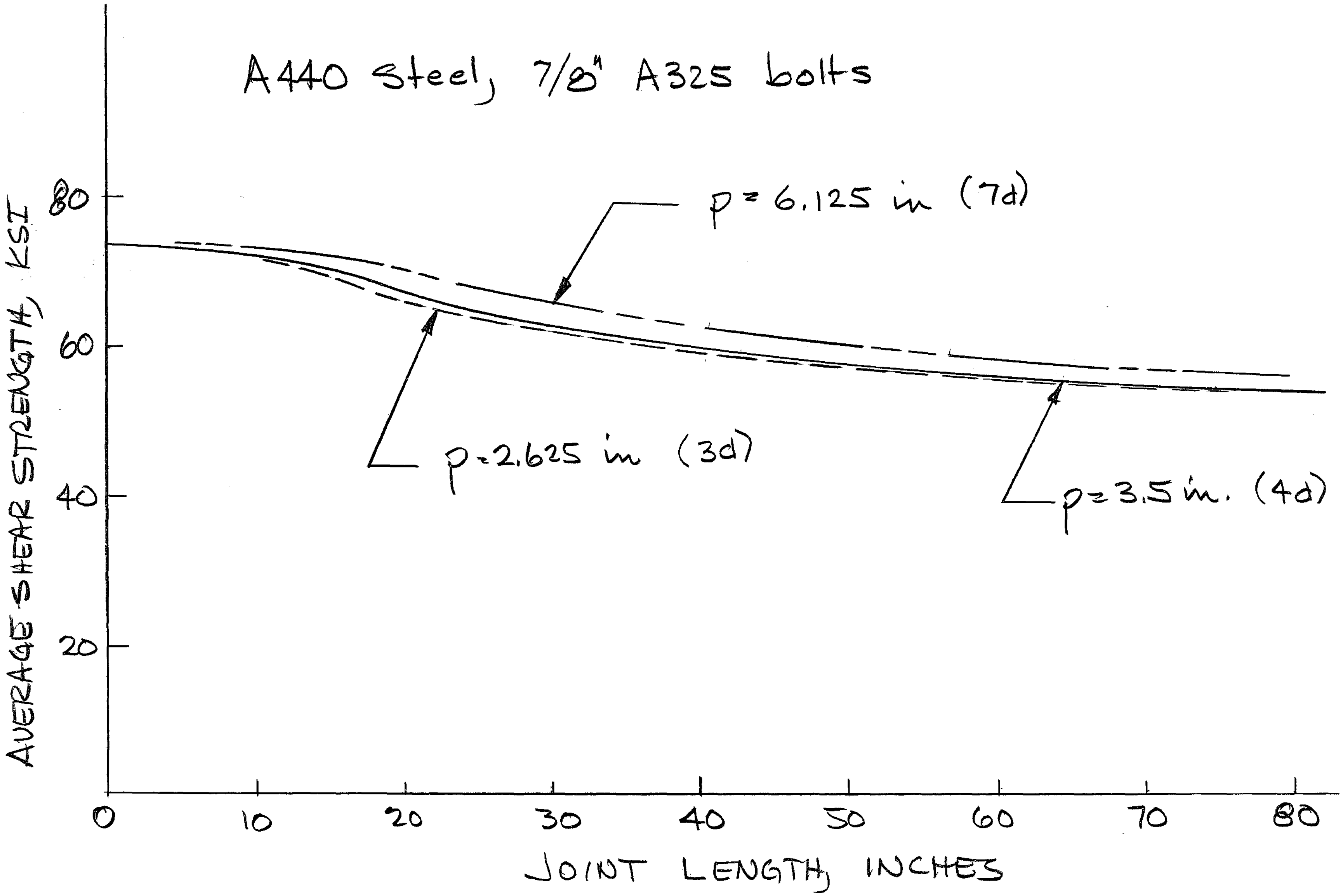


Fig. 6 Effect of Fastener Pitch on the Ultimate Strength

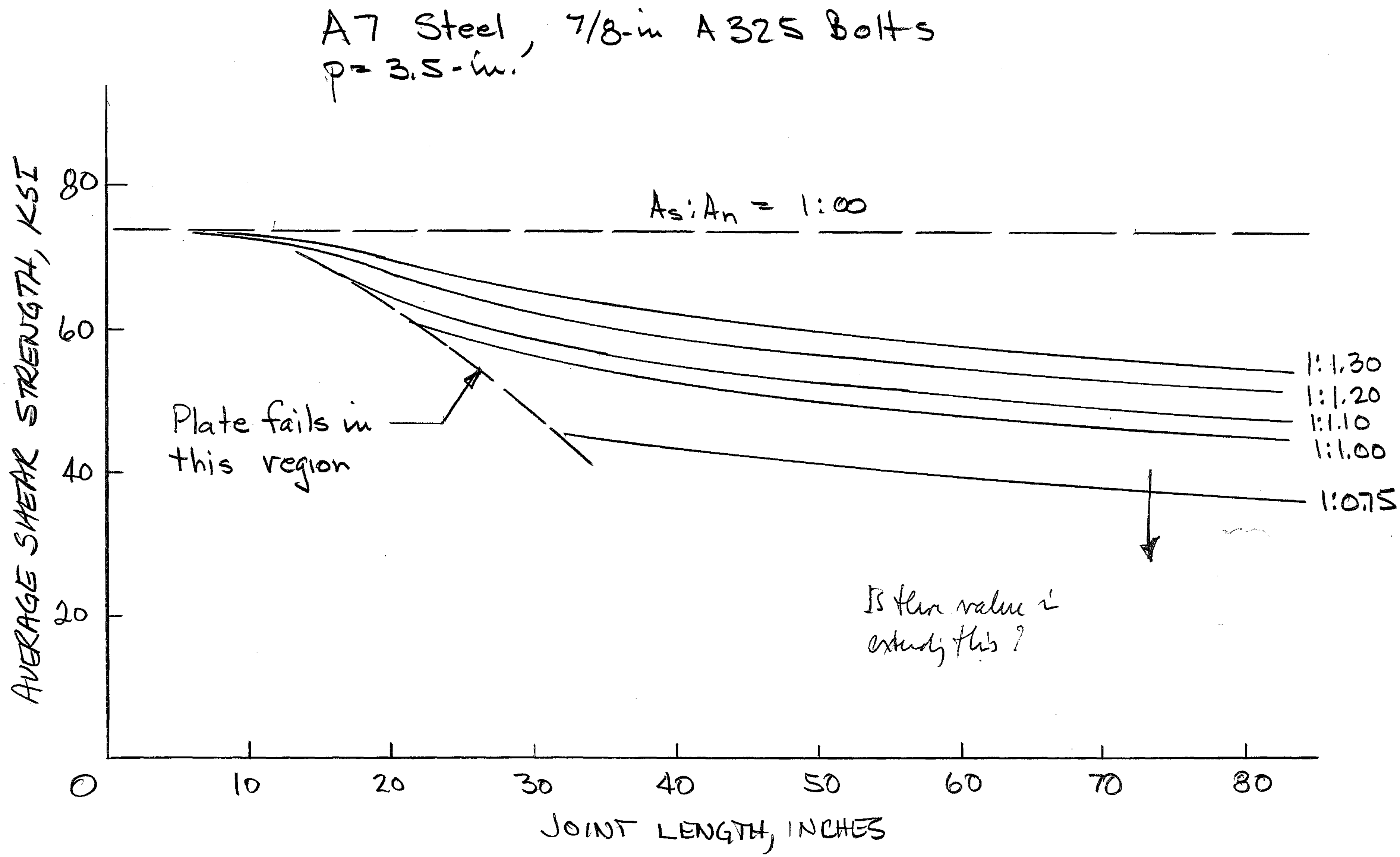
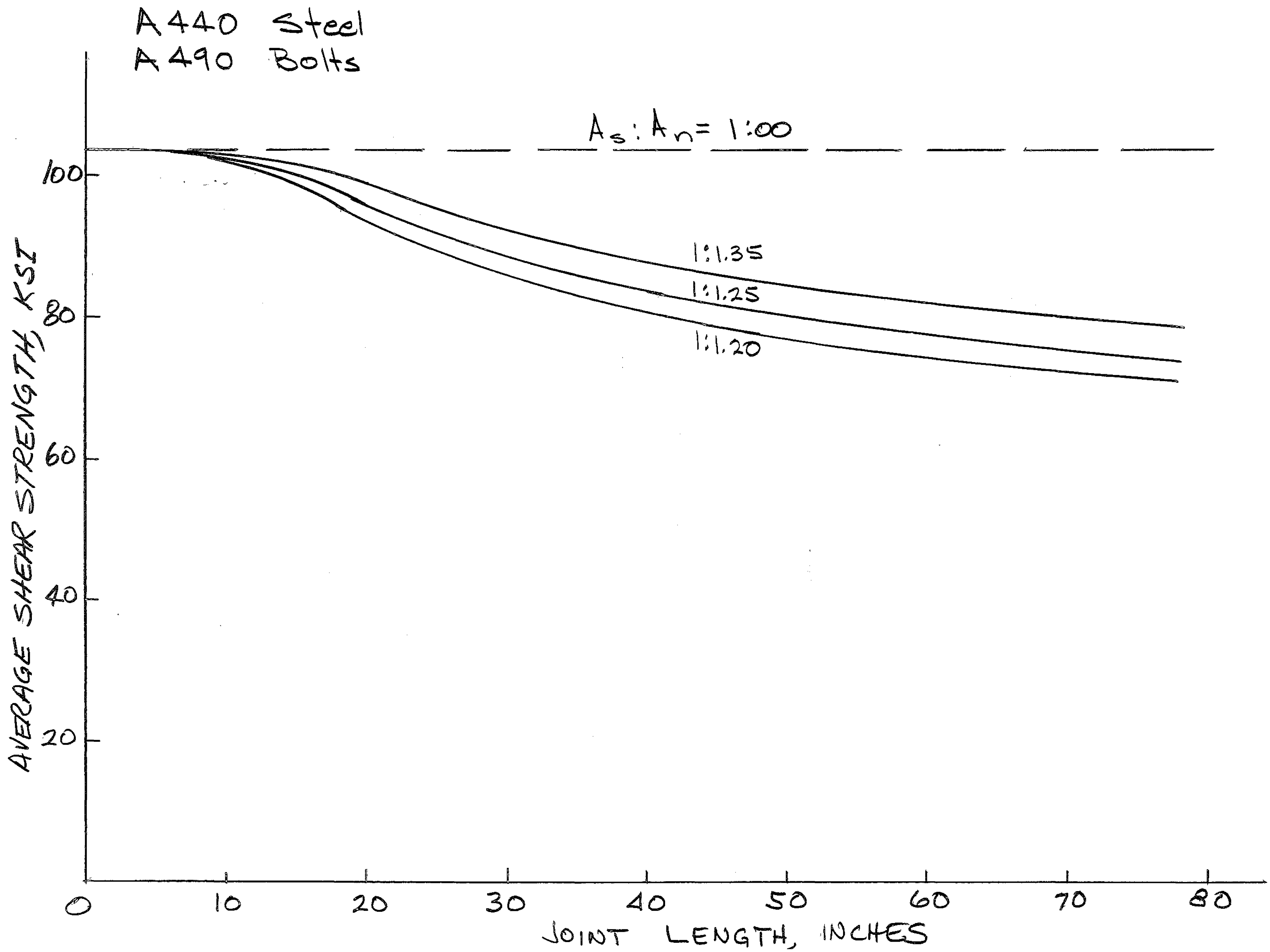


Fig. 7 Effective Variation in the Relative Proportions of the Bolt Shear and Net Tension Areas

more appropriate for someone else to study



211

Fig. A Effect of Variation in the Bolt Shear and Net Tension Areas - A440 Steel; A490 Bolts

SHEAR STRENGTH OF SINGLE ALLOY STEEL BOLTS

OBJECTIVE OF THE STUDY

This study was concerned with the behavior of single A354BC and A354BD (A490) bolts which were subjected to tension shear or compression shear loading. The effect of a number of variables on the ultimate shear strength and deformation at ultimate load was studied. The bolts used were manufactured from quenched and tempered carbon alloy steel in accordance with ASTM A354 - 58T.

DESCRIPTION OF BOLTS, TEST SPECIMENS AND TEST PROCEDURE

Table No. 1 gives a description of the six bolt lots that were used in the study. Three bolts per lot were tested in shear, with a total of 36 tested in compression shear and 15 tested in tension shear. It should be noted that all the shear planes passed through the bolt shank. For lots DC and FD, this necessitated milling approximately .13" and .20", respectively, off of the underside of the bolt head so that the shear plane did not pass through the thread runout. Two different steel types were used in the test jigs, A440 steel and constructional alloy steel (hereafter referred to as Q. and T. steel).

The tensile properties of the bolts can be found in Fritz Laboratory Report 288.9 "Calibration of A354 Bolts, Preliminary Report".

The compression and tension shear test jigs are shown in Figs. 1a and 1b respectively. The jigs were assembled with the bolts in bearing in order to minimize slip as much as possible. The faying surfaces were clean mill scale. All bolts were torqued to an elongation which corresponded to at least proof load.

The bolted jigs were tested in a 300 kip Universal testing machine. The test jigs containing the 7/8 in. diameter bolts were first loaded to 30 kips and the jigs containing 1 in. diameter bolts were loaded to 60 kips to insure removal of as much slip as possible. This load was subsequently removed and the actual testing then commenced.

The jigs were loaded slowly and deformation readings were taken every 10 kips until a deformation criterion controlled the load readings.

TEST RESULTS

Tables 2 and 3 summarize the results of the shear tests conducted on single alloy steel bolts for the compression and tension shear tests, respectively. All values given are the average of the three tests conducted. As of this writing, the tension shear tests using Q. and T. steel jigs have not been conducted.

A. Effect of Head Size

The effect of head size is shown in Fig. 2 by comparing lots AC and CC. The heavy head bolt showed no significant difference in behavior from the regular head bolts. The mean ultimate strength attained by the heavy head bolt was about 5 ksi higher than that attained by the regular head bolt. There was no significant difference in the deformations at ultimate load, irrespective of steel type. The variation between the regular head bolt and the heavy head bolt was no greater than the variation between different lots of regular head bolts.

B. Effect of Grip

The effect of grip can be found by comparing lots ED and GD and is shown in Fig. 3 for A440 steel jigs. Other steel types and loading condition load-deformation curves are similar. The greatest difference in ultimate load is 2.5 ksi; thus, there is no significant difference in behavior between a 4¼ in. grip and 8¼ in. grip test specimen. The deformations at ultimate were approximately the same.

C. Effect of Loading

This effect is shown in Fig. 4 where a typical load-deformation curve compares the tension shear strength with compression shear strength. The test results show that the compression shear test gives a 4% to 11% higher ultimate load as compared to the tension shear tests in A440 steel jigs. It is expected that the same trend will be observed in the Q. and T. jig tests. This reduction in strength is due to lap plate prying action, a phenomenon which tends to bend the lap plates of the tension jig outward. This induces an additional tensile component in the bolts which decreases its strength.

Also, for every case but one, the deformation at ultimate load was reduced by 4% to 19%. The FD lot deformation at ultimate load increased by 2% over the compression deformation.

D. Effect of Diameter

There seems to be no consistent trend in the variation of the average ultimate shear stress with bolt diameter, as can be seen by comparing lots CC vs. DC and EF vs. FD. Fig. 5 is a typical load-deformation curve showing the effect of this variable. Because of the larger bearing deformations, the total deformations for 1 in. diameter bolts were larger than those for 7/8 in. bolts.

E. Effect of Bolt Grade

The A354BD (A490) bolt has a higher carbon content than the A354BC bolt and will therefore sustain a higher load, as is borne out by the test data and shown in Fig. 6. However, for the same reason, the ductility of the A490 bolt is less than that of the A354BC bolt. This fact is borne out by the average deformations at ultimate load, which was greater for the A354BC bolts than for the A490 bolts.

F. Effect of Steel Type

Fig. 7 is a typical load-deformation curve showing the effect of this variable. There is no consistent trend in the variation of the average ultimate strength with the type of steel used for the test jig. However, because of the greater strength of the Q. and T. steel, the deformations at ultimate load were less than the deformations for A440 steel.

EFFECT OF END RESTRAINT IN TENSION JIGS

A series of three tension shear tests was run on 8B lot, A325 bolts in A440 steel jigs with the lap plate prying action minimized. It was found that the average load-deformation curve for this test approached that of the compression shear test for the same lot of bolts. Fig. 8 clearly shows this.

SHEAR-TENSILE STRESS RATIO

The average compression shear-tensile strength ratio (τ/σ) for the A354BC bolts is about the same as that for the A354BD bolts tested in compression shear, namely 0.708 and 0.718 respectively. The overall mean is 0.713. For the tension shear tests this ratio dropped to about 0.65.

It should be noted that the ratio is computed on the basis of the tensile stresses obtained from testing 0.505 inch diameter coupons cut from the A354 bolts. Since the shear planes all pass through the bolt shank, it seems unreasonable to include thread effects in the computation of the shear-tensile strength ratio. Also, the bolt tensile stresses, σ_B, are computed on the basis of a "stress area". Thus, it is more logical to compute the shear-tensile strength ratio on the basis of standard 0.505" diameter coupons.

SCATTER OF RESULTS

For a number of tests, there was quite a large scatter band. The maximum variation from the mean values for ultimate shear strength was $\pm$ 7.7 ksi. and for the deformation at ultimate load was $\pm$ 0.046 inches.

CONCLUSIONS

1. There is no significant effect on the ultimate shear strength or deformation by the head size or the grip length. (See Figs. 2 and 3).

2. The tensile shear strength is, on the average, 8% less than the compression shear strength for A354 bolts connecting A440 steel. Also, except for one case, the deformation at ultimate for tension shear was less than that for compression shear. (See Fig. 4).

3. There is no consistent trend in the variation of ultimate shear strength as influenced by bolt diameter. However, the deformations for the 1" diameter bolt is greater than that for the 7/8" diameter bolt. (See Fig. 5).

4. The A490 bolt is stronger in shear than the A354BC bolt. (See Fig. 6).

5. The type of connected steel affects the deformations at ultimate load. The higher the yield point of the connecting material, the less is the bearing deformation.

6. When lap plate prying action is eliminated, the tension shear strength approaches that of the compression shear strength.

7. The compression shear-tensile strength ratio for A354 bolts connecting A440 or Q. and T. steel is approximately 0.71, based on the tensile strength of 0.505" diameter coupons. The tension shear-tensile strength ratio is approximately 0.65.

BOLT LOTS USED IN SHEAR TESTS

Grade	Bolt Lot Mark	Diam.	Head	Length Under Head	Thread Length	Grip	Number Tested A440 Comp.	A440 Tension	Q. & T. Comp.	Q. & T. Tension
A354BC	AC	7/8	H	5¼	1-3/4	4-1/8	3	-	3	-
	CC	7/8	R	5½	2	4¼	3	3	3	3
	DC	1	R	5½	2¼	4-1/8	3	3	3	3
A354BD (A490)	ED	7/8	R	5½	2	4¼	3	3	3	3
	FD	1	R	5½	2¼	4-1/8	3	3	3	3
	GD	7/8	R	9½	2¼	8¼	3	3	3	3
							18	15	18	15

* All shear planes pass through the shank

Grip includes 1/8" washers.

Table 1. Bolt Description

COMPRESSION SHEAR

Lot	Bolt Type	Dia.	Grip	τ_A Avg. Shear Strength A440	τ_Q Avg. Shear Strength Q. & T.	Avg. Deformation A440	Avg. Deformation Q. & T.	σ_B, Tensile Strength	σ_c, Tensile Coupon Strength	$\frac{\tau_A}{\sigma_c}$	$\frac{\tau_Q}{\sigma_c}$
CC	A354BC	7/8"	4-1/4**	97.3 ksi.	91.3 ksi.	.2143 in.	.1607 in.	134.8 ksi.	133.0 ksi.	.731	.686
DC	A354BC	1	4-1/8*	95.2	96.5	.2500	.1688	137.0	131.6	.723	.733
ED	A354BD	7/8	4-1/4**	110.0	116.0	.1810	.1482	168.3	164.9	.667	.704
FD	A354BD	1	4-1/8*	115.0	111.4	.2293	.1760	163.8	149.8 ?	.767	.744
GD	A354BD	7/8	8-1/4**	112.3	116.8	.1960	.1500	163.3	160.9	.700	.725
AC	A354BC	7/8	4-1/8*	96.6	96.3	.2217	.1583	140.8	140.4	.687	.685

* Grip includes on hardened washer.

** Grip includes two hardended washers.

Table 2. Compression Shear Results

why not drop it?

John: why is this ratio important?

TENSION SHEAR

Lot	Bolt Type	Dia.	Grip	Avg. Shear Strength A440	Avg. Shear Strength Q. & T.	Avg. Deformation A440	Avg. Deformation Q. & T.	σ_B, Tensile Strength	σ_c, Tensile Coupon Strength	$\frac{\tau_A}{\sigma_c}$	$\frac{\tau_Q}{\sigma_c}$
CC	A354BC	7/8	4-1/4	86.3 ksi.	*	.1781 in.	*	134.8 ksi.	133.0 ksi	.649	
DC	A354BC	1	4-1/8	88.2		.2123		137.0	131.6	.670	
ED	A354BD	7/8	4-1/4	103.3		.1736		168.3	164.9	.626	
FD	A354BD	1	4-1/8	100.3		.2338		163.8	149.8	.671	
GD	A354BC	7/8	8-1/4	102.1		.1700		163.3	160.8	.636	
AC**	A354BC	7/8	4-1/8					140.8	140.4		

* Tests with Q. & T. jigs not complete.

** Tests found to be unnecessary.

Table 3. Tension Shear Results

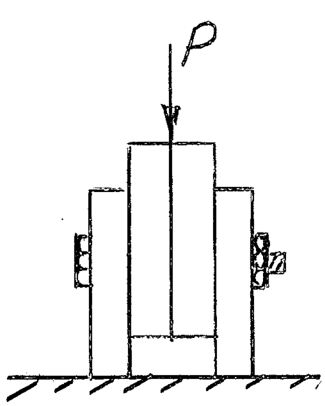


Fig. 1a

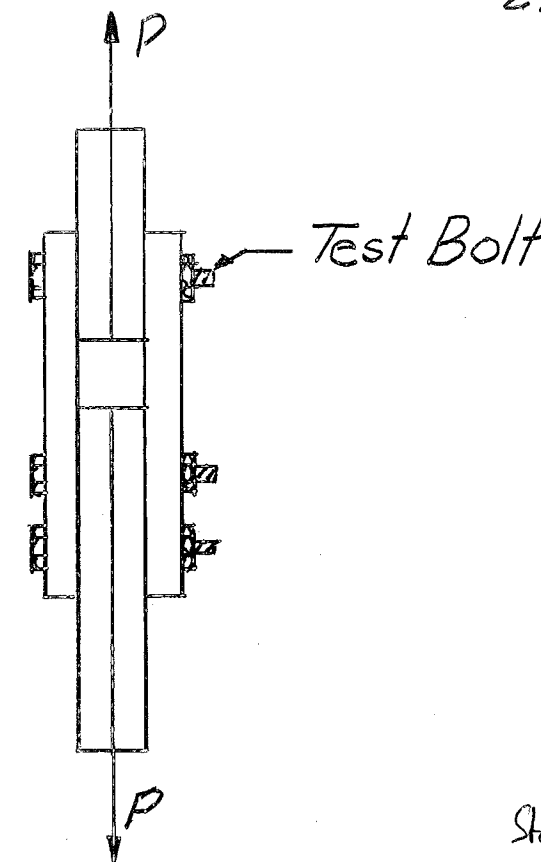


Fig. 1b

Static
or dynamic
loading?

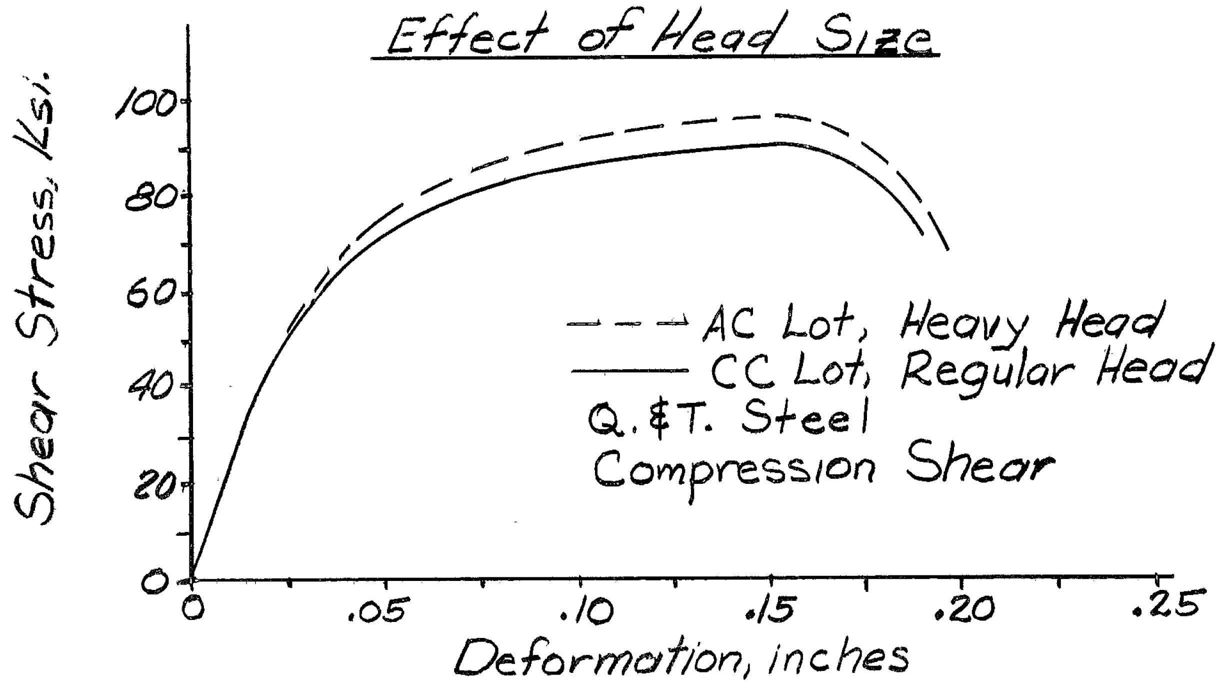
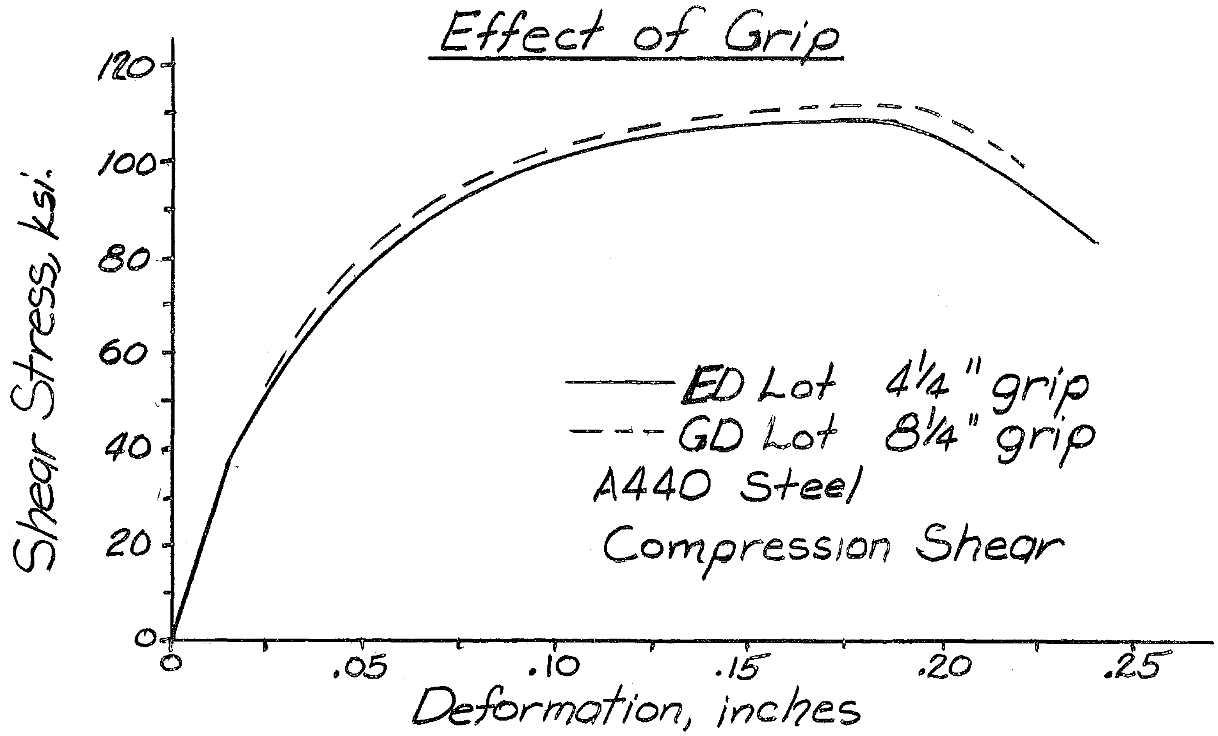


Fig. 2 Effect of Head Size

Need
test points



Is it grip or span?

Fig. 3 Effect of Grip

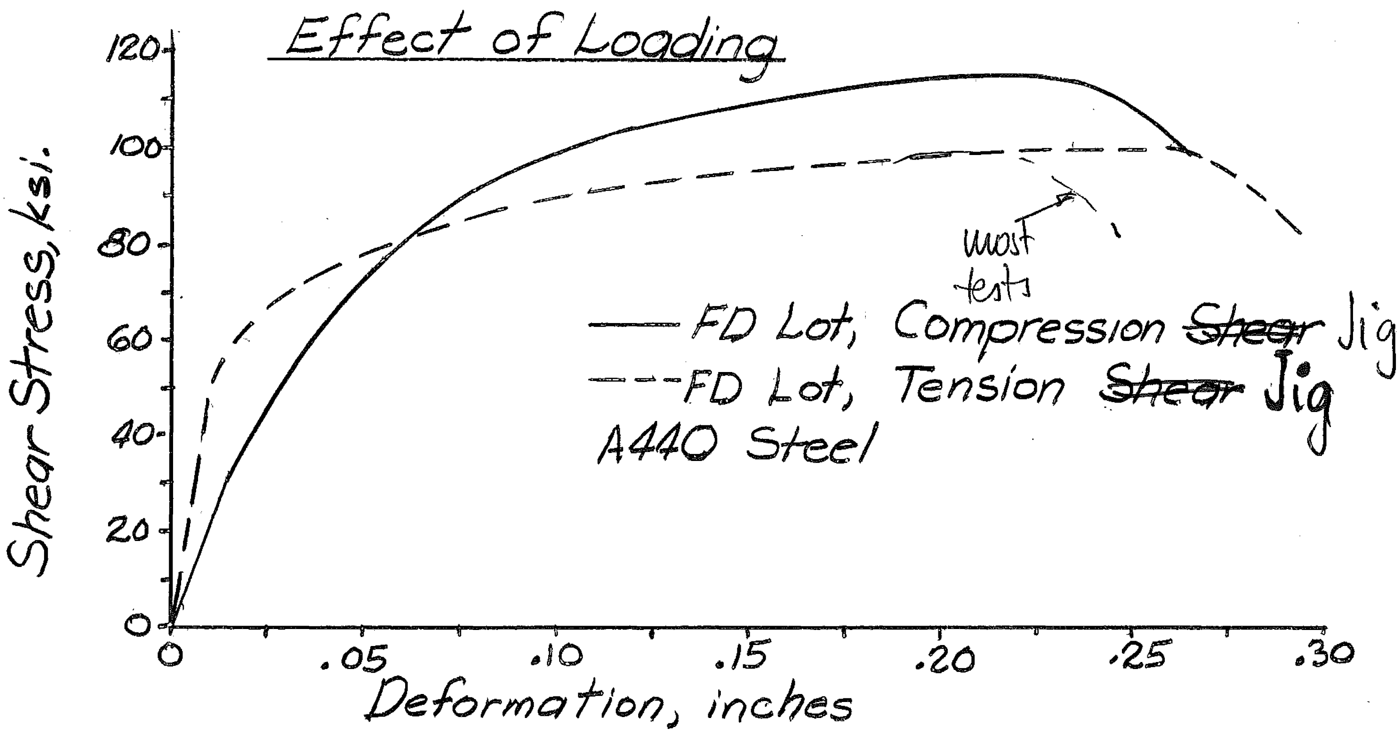


Fig. 4 Effect of Loading

?

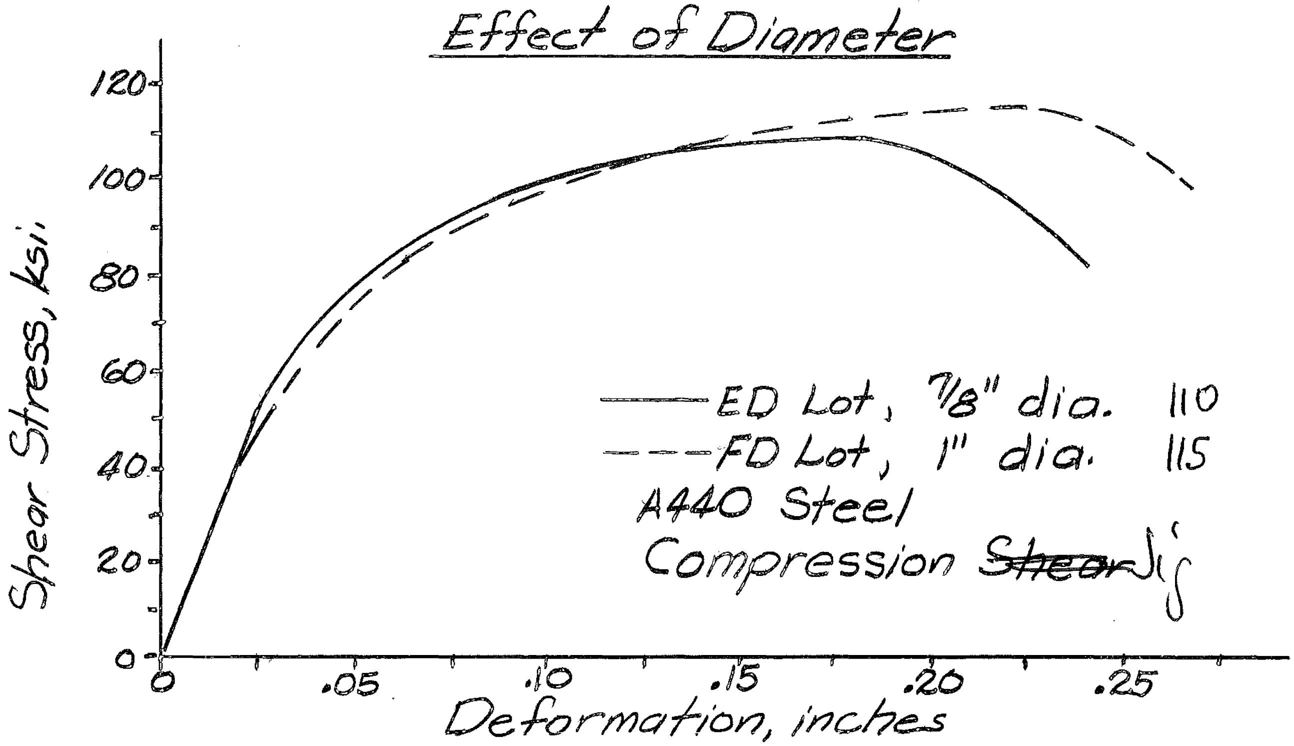


Fig. 5 Effect of Diameter

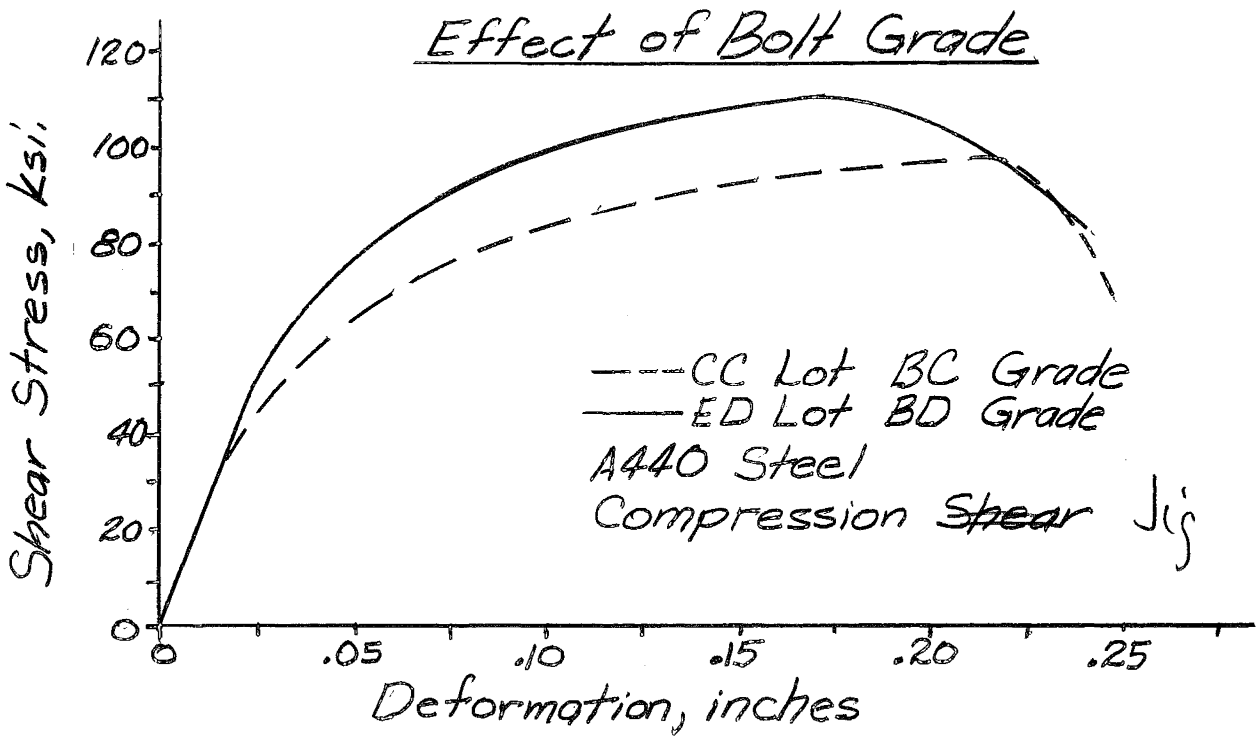


Fig. 6 Effect of Bolt Grade

Effect of ~~Steel~~ Type of Steel in Jig

Be careful of this conclusion. The deformations are important

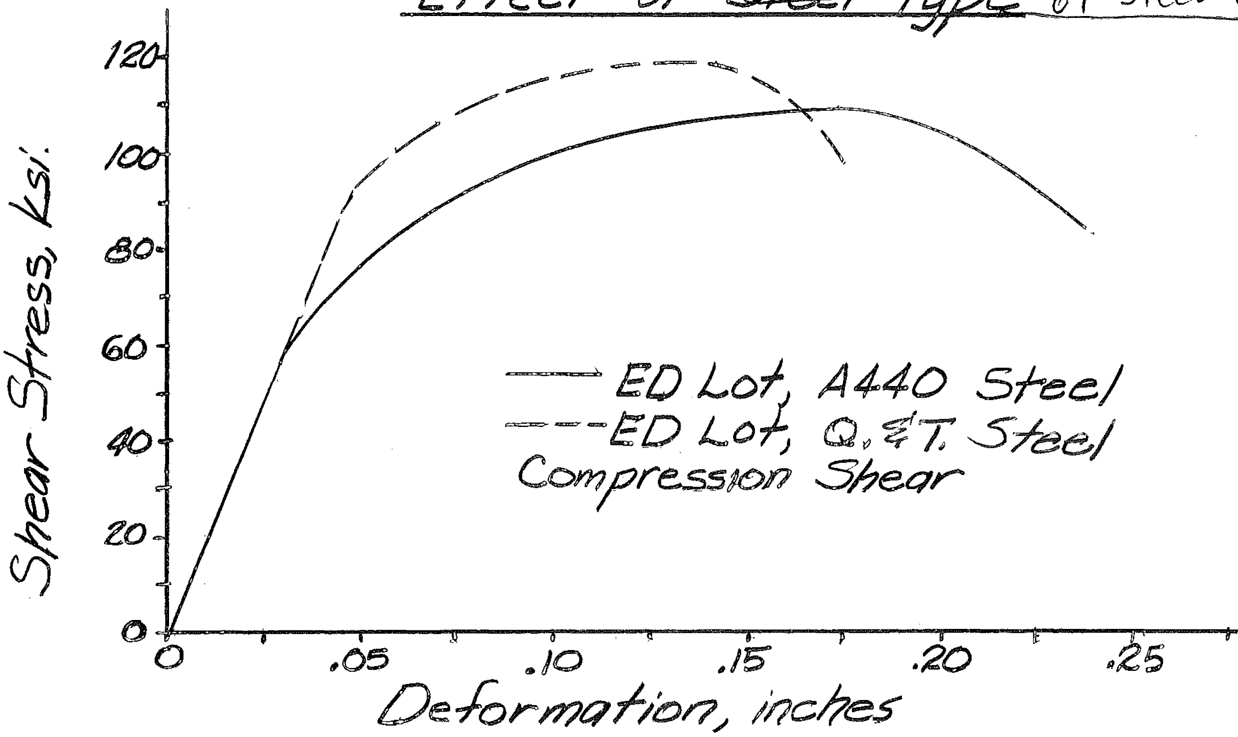


Fig. 7 Effect of Steel Type

Effect of End Restraint

8B Lot, A325 Bolts

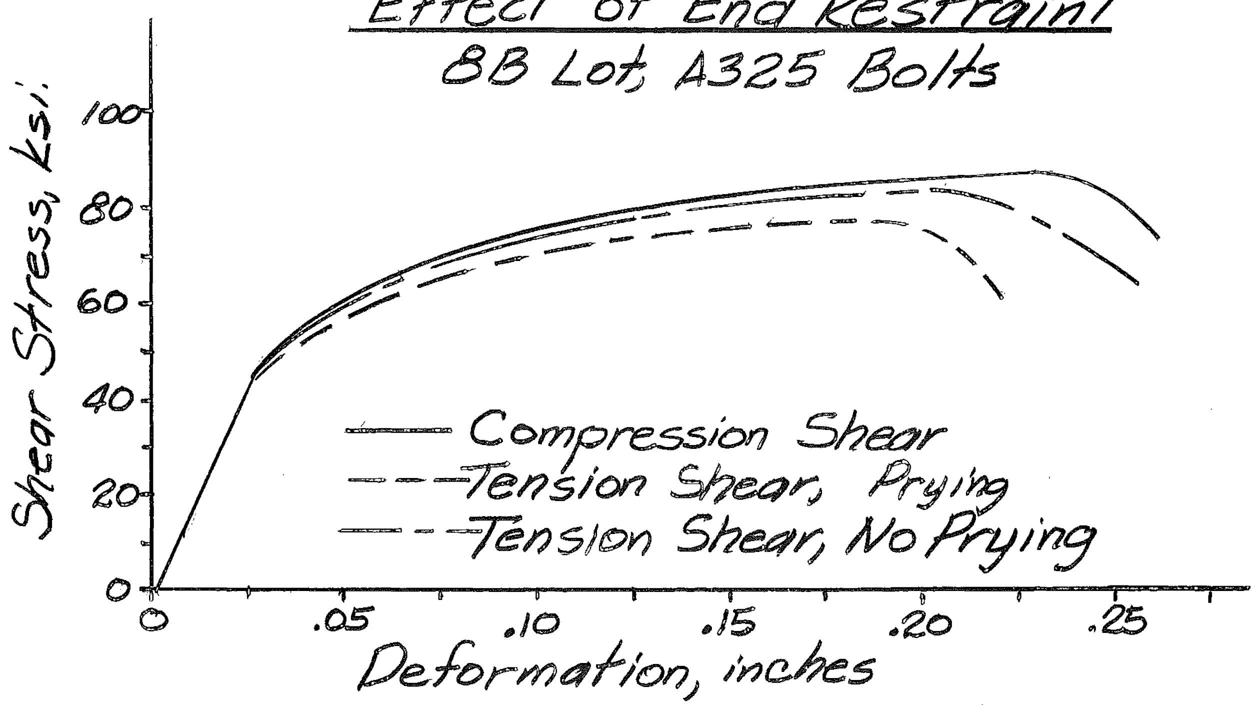


Fig. 8 Effect of End Restraint

LEHIGH PRELIMINARY REPORT - COOPERATIVE STUDY OF A490 BOLTS

INTRODUCTION

At the February 14, 1963 meeting of Committee 15 of the Research Council on Riveted and Bolted Structural Joints it was recommended that Lehigh and Illinois Universities conduct tests on bolts from the same lot to determine if testing procedures consistute a variable. Each University was to test bolts in direct and torqued tension using their own standard calibration procedures.

The results of twenty direct tension and thirty torqued tension tests are given in this report. These tests constitute the work done at Lehigh on this study.

TEST PROCEDURE

a) General

Two lots of 7/8" diameter, heavy hexagon head, A490 bolts were tested. Bolts in the AB lot were 9-1/2" long with 1-1/2" of cut thread; bolts from Lot LI were 5-1/2" long with 1-1/2" of rolled thread. In all tests A194 Grade 2H nuts (heavy hexagon), with a hardened washer were used. Two grip lengths were investigated, namely 4 inches and 8 inches. Each nominal grip had two lengths of thread under the nut, 1/8" or 9/16".

b) Torqued Tension Tests

For all torqued tension tests the bolt-nut threading was checked by running a nut up the bolt thread to runout. If this could not be accomplished by "finger tightening" only, this bolt-nut combination was rejected. ~~Each~~ The AB lot of bolts was checked for fit with NC2A go and no-go ring gages and each nut was checked with NC2B go and no-go plug gages. The torqued tension tests were conducted on the Model M Skidmore-Wilhelm calibrating device and in a block of solid A440 steel.

In the Skidmore-Wilhelm device the bolt was hand tightened to a "snug" load of 10 kips, in two five kip increments from "finger tight", with load, elongation and "turn-of-the-nut" being measured at each load interval. The nut was then rotated in 45° (1/8 turn) increments with a pneumatic impact wrench until failure. Load and elongation measurements were taken at each increment of turn.

In the solid steel plate a "snug" elongation, equal to the mean elongation determined at ten kips in the Skidmore-Wilhelm device, was applied. Nut rotation-elongation readings were taken for each 1/8 turn-of-the-nut.

For all torqued tension tests a CP612 pneumatic impact wrench, with a new 7/8" socket supplied by the University of Illinois, was used.

c) Direct Tension Tests

As a preliminary test the bolts were loaded to the specified proof-load and then unloaded to check the ASTM requirement of minimum permissible set (0.0005 in.). No bolts were rejected by this test. The direct tension tests were conducted in a 300 kip Baldwin hydraulic testing machine at a speed of 0.01" per minute.

TEST RESULTS AND CONCLUSIONS

Table 1 and Figures 1 through 6 summarize the test results. Figures 4 and 5 show the broad scatter associated with the torqued tension tests of the LI lot bolts.

AB Lot

(1) The length of thread in grip had a pronounced effect on the number of turns to failure, with the longer grip requiring more rotation.

(2) The ultimate strength of the bolts tested in direct tension was 10 to 13 percent greater than that obtained in torqued tension.

(3) A lesser amount of exposed thread under the nut resulted in an increase in the ultimate strength, in both torqued and direct tension tests. (See Figures 1 and 2).

(4) Proof load was not reached at 1/2 turn-of-the-nut from "snug" with either 1/8" or 9/16" thread in the grip when tested in the calibrating device.

LI Lot

(1) An average of 1-1/4 turns-of-the-nut were required to fail specimens with 1/8" thread in grip, and an average of 1-9/16 turns were required for those with 9/16" thread in grip.

(2) The ultimate strength of the bolts tested in direct tension showed a 20 - 23 percent increase over those tested in torqued tension.

(3) An increase in grip length (i.e. more thread in grip) resulted in a decrease in the ultimate strength in both torqued and direct tension tests. (See Figures 3 and 4).

(4) In specimens tested in the Skidmore-Wilhalm device proof load was reached at 1/2 turn-of-the-nut from "snug" only for 3 of the ten bolts tested. The average load value at 1/2 turn was below proof load in both cases (i.e. 1/8" and 9/16" thread in grip).

(5) Figure 5 indicates that the specimens torqued in solid steel did reach proof load at 1/2-turn from "snug"; and also they indicate that fewer turns-of-the-nut are required in solid steel than in the Skidmore-Wilhelm device to achieve the same elongation (and therefore, load).

TABLE 1

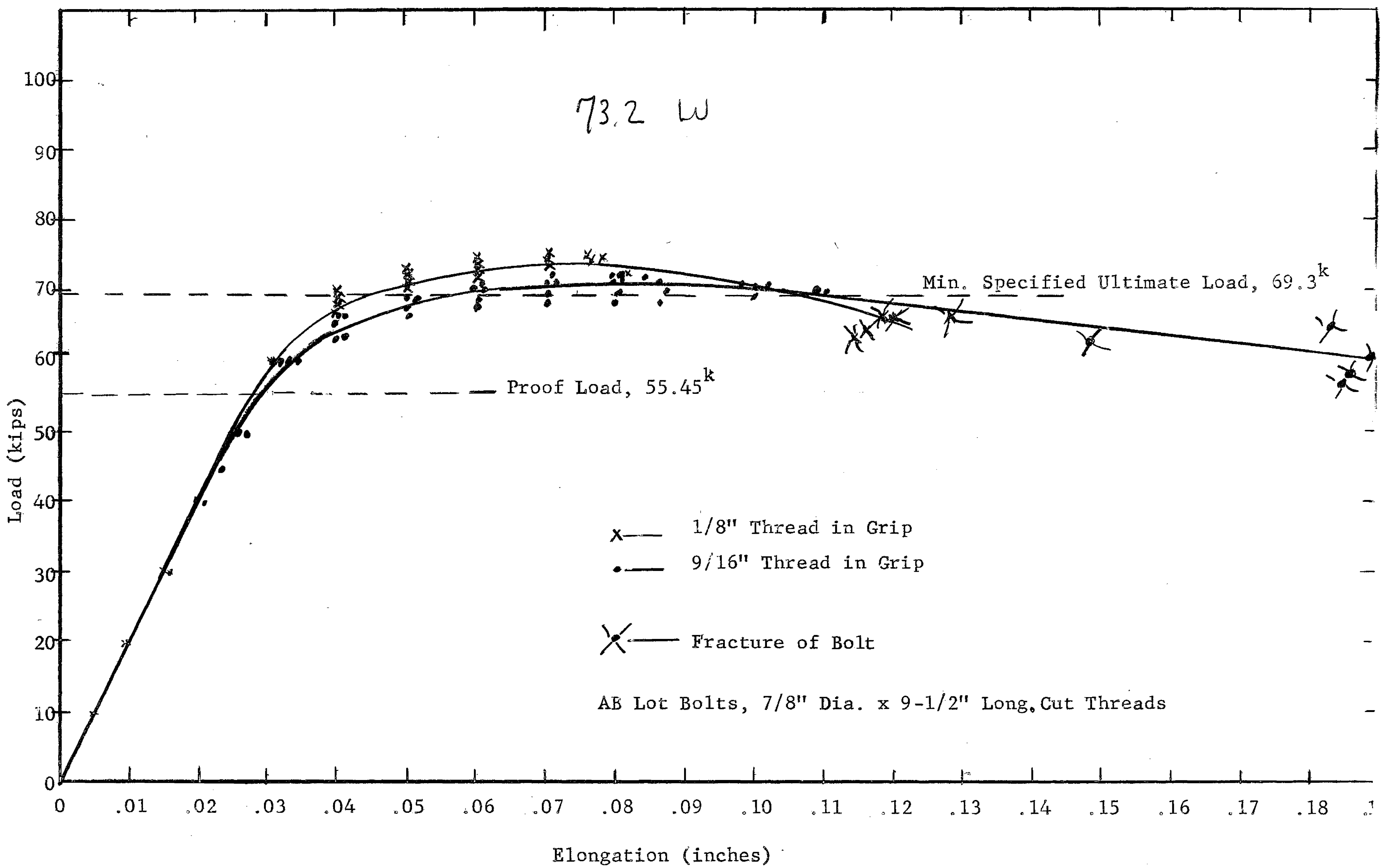
					LOT AB				LOT LI
Bolt Length	in.				9½				5½
Thread Length	in.				1.50				1.50
Spec. Proof Lo	kips				55.45				55.45
Spec. Min. Ultoad	kips				69.3				69.3
DIRECT TENSION CALIBRATION									
		L	I	I	L	L	I	I	L
Nominal Grip	in.	8½	8½	8-5/8	8-5/8	4-1/8	4-1/8	4-9/16	4-9/16
Thread in Grip	in.	1/8	1/8	9/16	9/16	1/8	1/8	9/16	9/16
No. of SpecimeTested		5	6	5	5	5	5	4	5
Mean Ult. Load	kips	73.2	73.6	69.8	70.8	76.0	75.8	72.1	72.1
Standard Devian	kips	1.59	1.75	1.33	1.69	.54	0.50	0.90	.17
Mean Elong. att. Load	in.	.0779	.0740	.0794	.0846	.0508	.0471	.0610	.0647
Mean Rupture L	kips	65	66	62	61	67	68	61	59
Mean Elong. atpture	in.	.12	-	-	.18	.137	-	-	.245
Mean Elong. atoof Load	in.	.0282	.027	.030	.0292	.0154	.0145	.0165	.0171
% Spec. Min. U Load		106	106	101	102	110	109	104	104
TORQUED TENSION CALIBRATION - in Skidmore-Wilhelm									
		L	I		L	L	I		L
Thread in Grip	in.	1/8	1/8	9/16	9/16	1/8	1/8	9/16	9/16
No. of SpecimeTested		5	5	5	5	5	3	3	5
Mean Ult. Load	kips	65.4	65.4	60.0	61.8	61.1	63.3	60.2	58.4
Standard Devian	kips	2.80	3.40	0.80	2.18	2.80	3.40	2.80	3.00
Mean Elong. att. Load	in.	.0525	.0553	.0616	.0698	.0260	.0252	.0360	.0310
Mean Rupture I	kips	52	-	-	50	40	-	-	34
Mean Elong. af Rupture	in.	.08	-	-	.114	.075	-	-	.11
Mean Elong. atoof Load	in.	.028	.028	.033	.031	.016	.016	.018	.018
Mean Load at ½rn from "snug"	kips	48.8	49.0	47.0	41.1	53.4	56.5	53	50.0
(Torqued TensiUlt.): (Direct Tens Ult.)		.90	.89	.86	.87	.80	.84	.84	.77
Ave. Turns to lure		1.37	1.42	1.64	1.87	1.25	1.38	1.64	1.56

Note: L = Leh
I = Ilois

TABLE 1

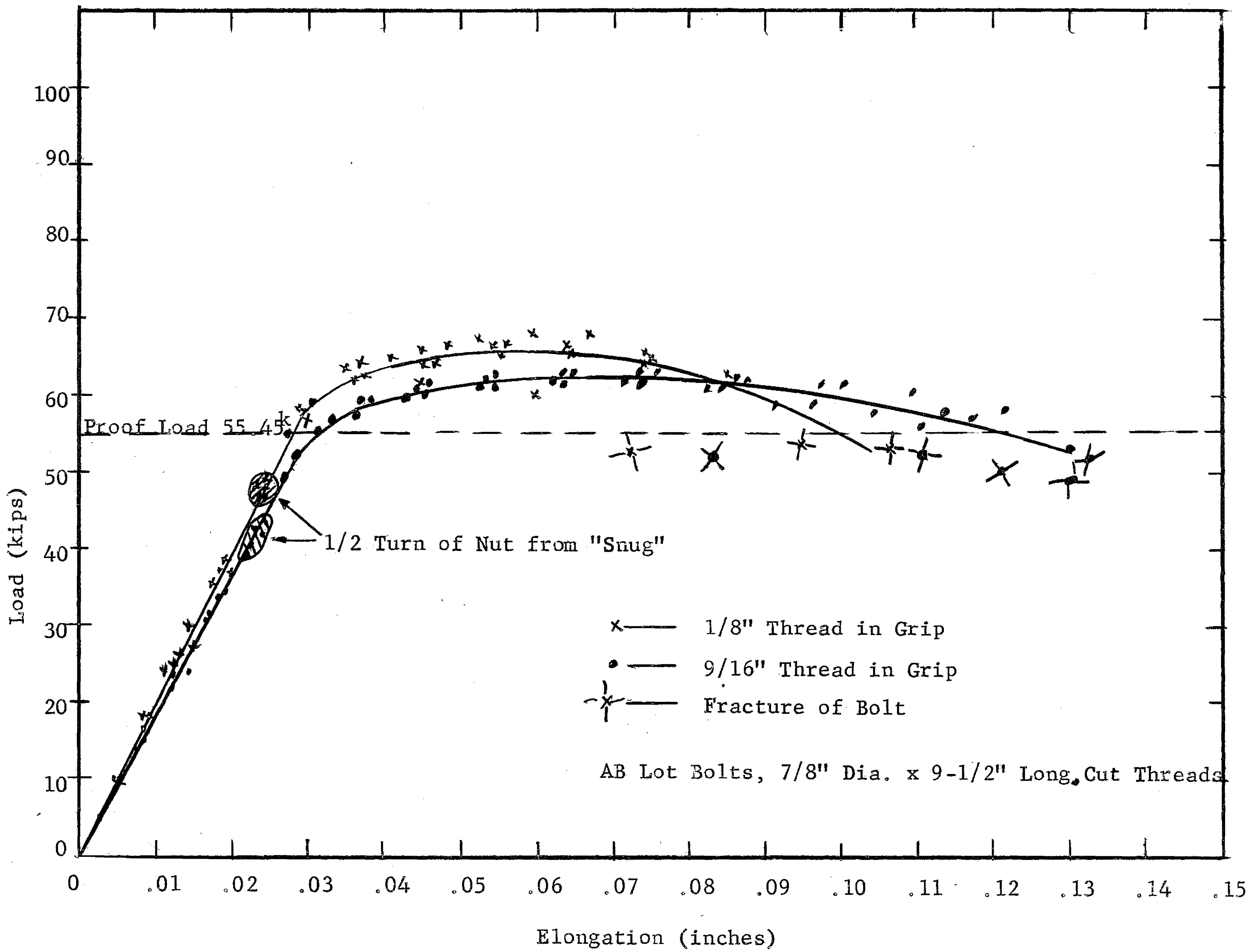
		LOT AB				LOT LI			
Bolt Length	in.	9½				5½			
Thread Length	in.	1.50				1.50			
Spec. Proof Load	kips	55.45				55.45			
Spec. Min. Ult. Load	kips	69.3				69.3			
DIRECT TENSION CALIBRATION									
		L	I	B	L	L	I	B	L
Nominal Grip	in.	8	8	8	8	4	4	4	4
Thread in Grip	in.	1/8	1/8	1/8	9/16	1/8	1/8	1/8	9/16
No. of Specimens Tested		5			5	5			5
Mean Ult. Load	kips	73.2			70.8	76.0			72.1
Standard Deviation	kips	1.59			1.69	.54			.17
Mean Elong. at Ult. Load	in.	.0779			.0846	.0508			.0647
Mean Rupture Load	kips	65			61	67			59
Mean Elong. at Rupture	in.	.12			.18	.137			.245
Mean Elong. at Proof Load	in.	.0282			.0292	.0154			.0171
% Spec. Min. Ult. Load		106			102	110			104
TORQUED TENSION CALIBRATION - in Skidmore-Wilhelm									
		L	I	B	L	L	I	B	L
Thread in Grip	in.	1/8	1/8	1/8	9/16	1/8	1/8	1/8	9/16
No. of Specimens Tested		5			5	5			5
Mean Ult. Load	kips	65.4			61.8	61.1			58.4
Standard Deviation	kips	2.80			2.18	2.80			3.00
Mean Elong. at Ult. Load	in.	.0525			.0698	.0260			.0310
Mean Rupture Load	kips	52			50	40			34
Mean Elong. after Rupture	in.	.08			.114	.075			.11
Mean Elong. at Proof Load	in.	.028			.031	.016			.018
Mean Load at ½ turn from "snug".	kips	48.8			41.1	53.4			50.0
(Torqued Tension Ult.): (Direct Tension Ult.)		.90			.87	.80			.77
Ave. Turns to Failure		1-3/8			1-7/8	1-1/4			1-9/16

Note: L = Lehigh
I = Illinois
B = Both



DIRECT TENSION CALIBRATION AB-LOT BOLTS

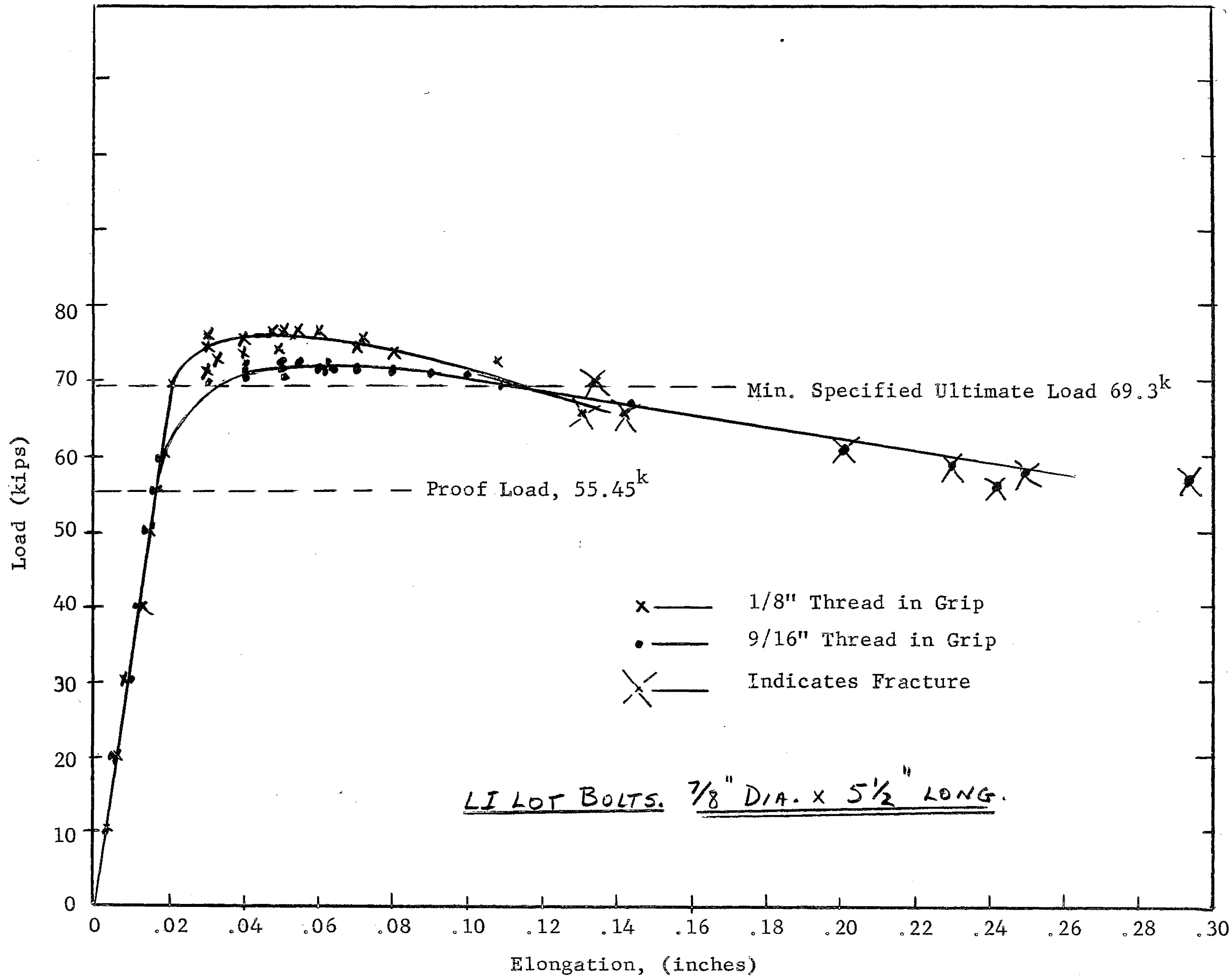
FIG. 1



TORQUED-TENSION CALIBRATION AB-LOT BOLTS

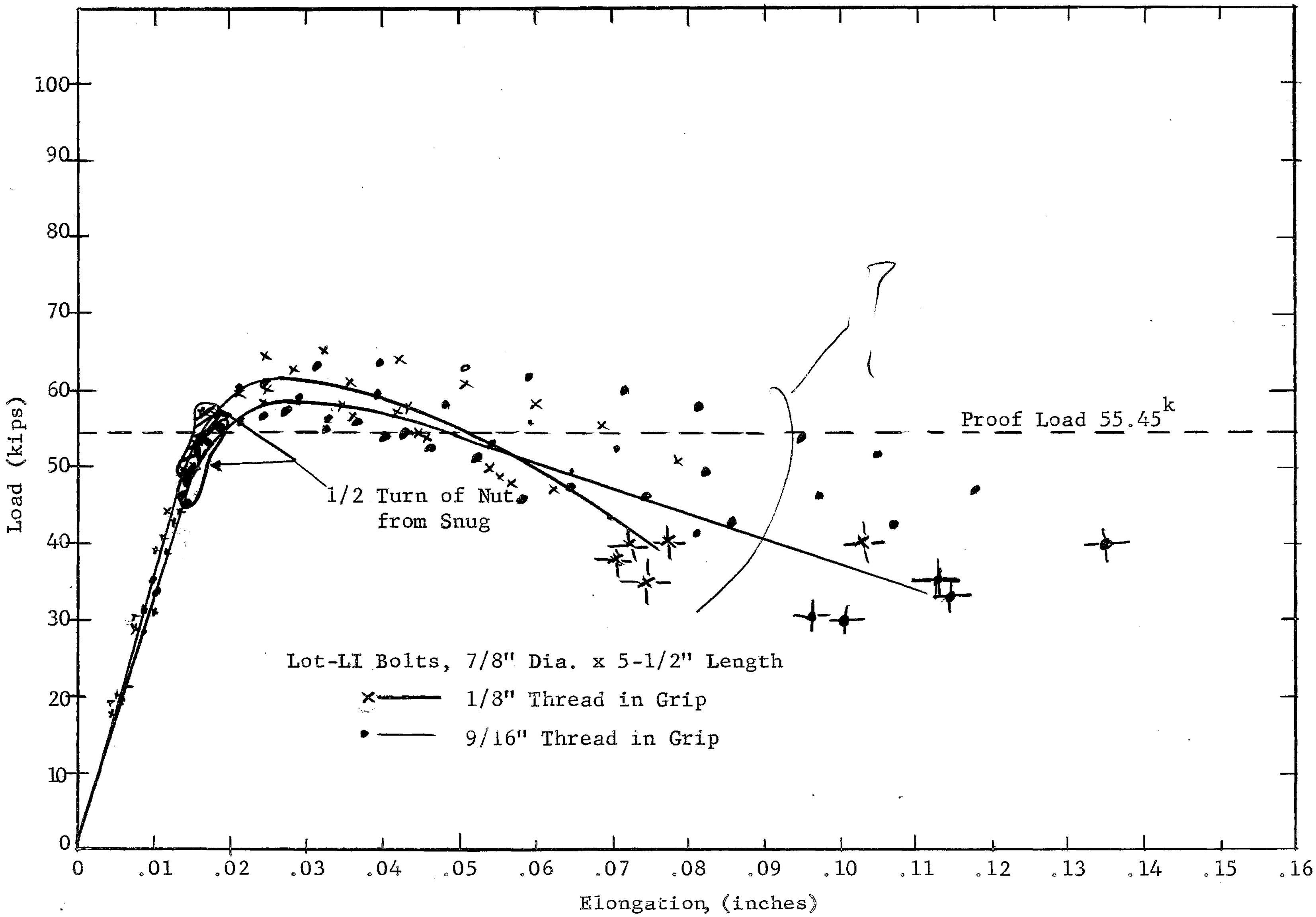
FIG. 2

Jan (late)
mtg of Spec
Com.



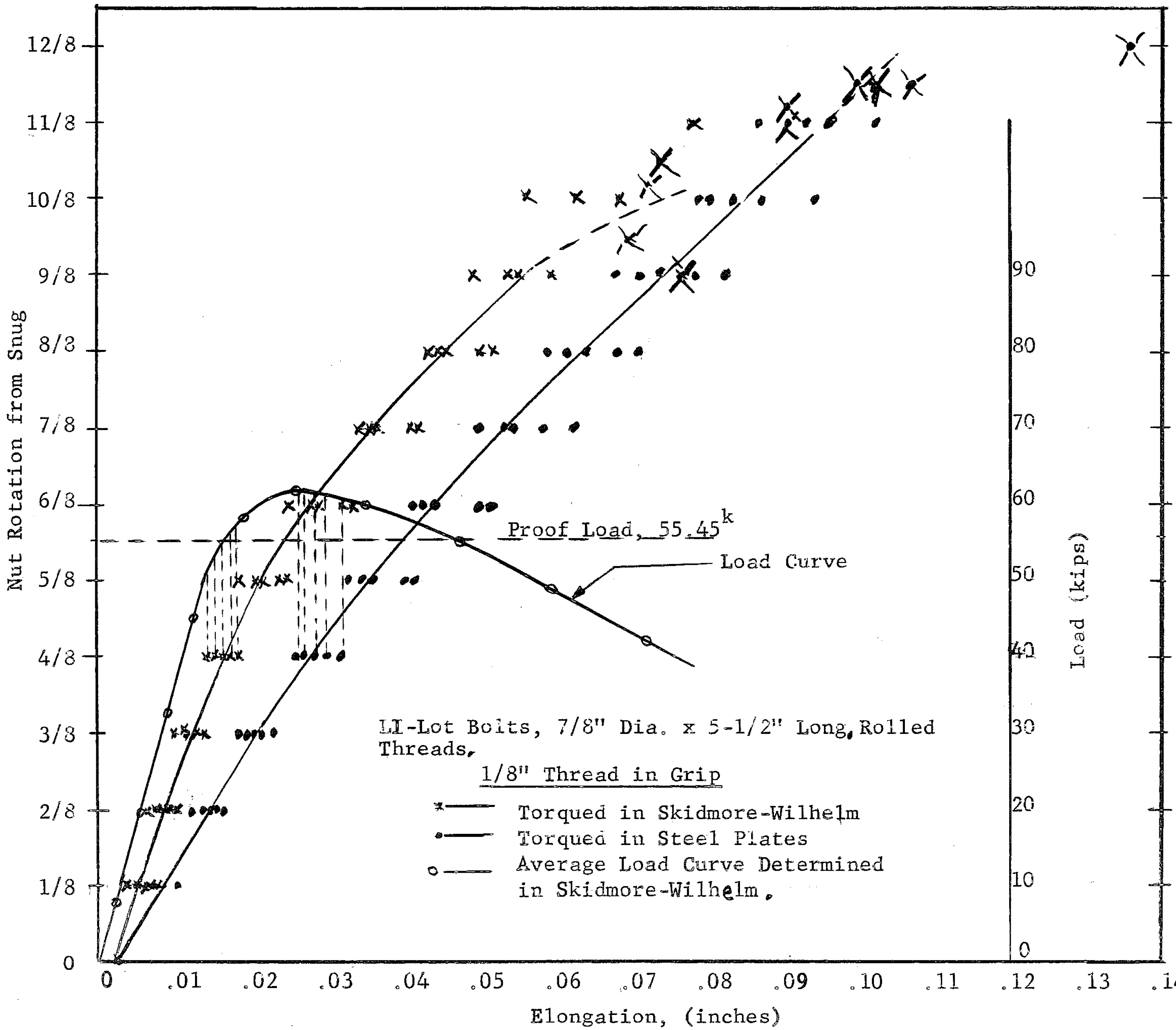
DIRECT TENSION CALIBRATION - LI-LOT BOLTS

FIG. 3



TORQUED TENSION CALIBRATION ON LI-LOT BOLTS

FIG. 4



ELONGATION-NUT ROTATION CHARACTERISTICS OF LI-LOT BOLTS TORQUED IN SKIDMORE-WILHELM AND IN SOLID STEEL

FIG. 5

Don't cut off your stuff

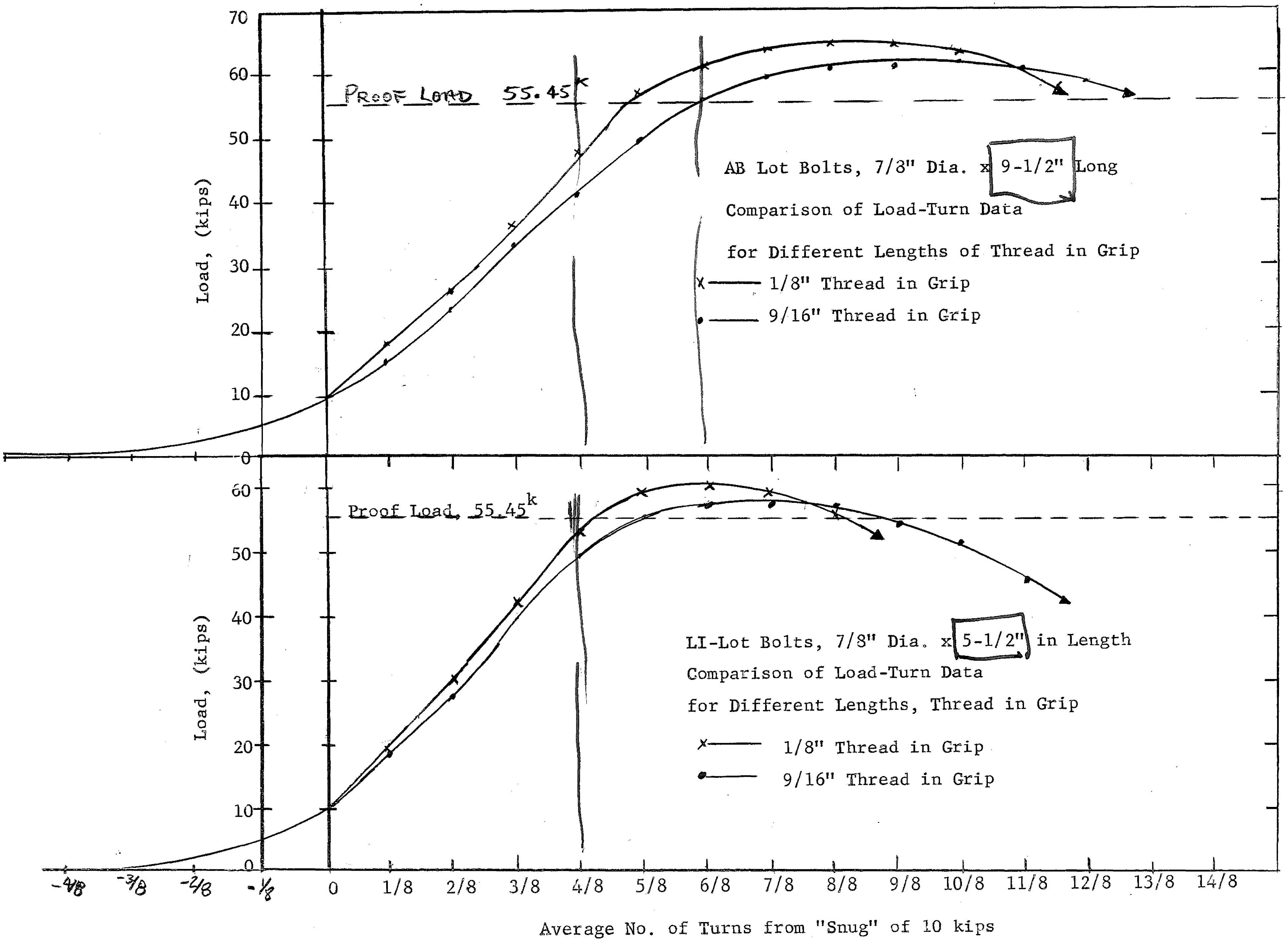

PROOF LOAD 55.45k
AB Lot Bolts, 7/8" Dia. x 9-1/2" Long
Comparison of Load-Turn Data
for Different Lengths of Thread in Grip
1/8" Thread in Grip
9/16" Thread in Grip
Proof Load 55.45k
LI-Lot Bolts, 7/8" Dia. x 5-1/2" in Length
Comparison of Load-Turn Data
for Different Lengths, Thread in Grip
1/8" Thread in Grip
9/16" Thread in Grip
Load, (kips)
Load, (kips)
0
10
20
30
40
50
60
70
-4/8
-3/8
-2/8
-1/8
0
1/8
2/8
3/8
4/8
5/8
6/8
7/8
8/8
9/8
10/8
11/8
12/8
13/8
14/8
Average No. of Turns from "Snug" of 10 kips

FIG. 6

FURTHER TENSILE TESTS OF A354 BOLTS

1. REVIEW

This report is a continuation of the preliminary report, "Calibration of A354 Bolts", Fritz Engineering Laboratory Report No. 288.9(1). As a review, this preliminary report included the results of the direct and torqued tension tests of A354 bolts, grades BC and BD. Some of the more important conclusions reached in this report were:

1. The ultimate strength of the bolts when tested in direct tension was from 6 to 27 percent higher than that obtained during the torqued tension tests. This effect has also been noted in previous tests of A325 and A354 bolts at Lehigh and the University of Illinois.

2. The average preload induced by torquing the bolts ½ turn (180°) of nut from a "snug" load of 8 kips was just above proof load for most lots of bolts with grip lengths up to 4¼ inches. For the longer grips of 7-5/8 to 8-1/8 inches, the load at ½ turn of nut was always below proof load.

3. Thread lubrication had, at most, a slight beneficial effect on the behavior of torqued bolts.

4. Failure of bolts torqued with an impact wrench occurred after 1 to 1-7/8 revolutions, depending on bolt size and grade, and on the length of thread in the grip. These correspond to rotational factors of safety from 2.0 to 3.75 if one half turn of nut is specified for installation.

Figure 1 shows typical load-deformation relationships for the A354 bolt, and also illustrates graphically the first three conclusions stated above.

Since this report was written, several special tests have been conducted to determine other tensile properties of the A354 bolt. These tests included:

1. Direct tension tests of bolts previously installed by torquing.

2. Repeated installation of bolts by torquing.

3. Torqued tension tests of bolts installed in solid plates.

4. Torqued tension tests of bolts torqued continuously rather than in small increments.

Following are the results of these tests:

2. TEST RESULTS

2.1 Effects of Installation

Direct tension tests of bolts previously installed by torquing are conducted to determine the reduction, if any, in direct tension strength of a bolt previously installed with an impact wrench. Figure 2 shows typical results of these combined torqued tension and direct tension tests. The bolts were first torqued to 5/8 of a turn after which additional load was applied in direct tension. Also shown in this figure are the load elongation relationships for the direct tension and for the torqued tension tests of the same lot of bolts. It can be seen that when direct tension is applied to the torqued bolt, it has an ultimate strength approximately equal to that of the bolt tested in direct tension alone.

Four representative lots of bolts were tested in this manner and the ultimate strength for each lot was within 3 percent of the ultimate strength for direct tension tests of the same lot.

2.2 Repeated Installation

As implied, the purpose of these tests is to determine the feasibility of reusing previously installed bolts. Shown in Fig. 3 is the load-elongation relationship for a bolt repeatedly torqued to 3/4 turn of nut from snug. In Fig. 4, the behavior of a bolt from the same lot torqued to ½ turn is shown. From these figures it can be seen that the reaction of these bolts to reuse was very critical. For cycles of 3/4 turn of nut, only two cycles were completed before failure and for cycles of ½ turn of nut, only three cycles were completed. This behavior was much more severe than that shown in earlier tests of A325 bolts, and was typical of all four lots tested, including both BC and BD grades.

It should also be mentioned that, after the first installation, required torquing time increased substantially.

2.3 Bolts Torqued in Solid Plates

These tests were conducted as a result of the belief that the deformation under load of a hydraulic load cell such as the bolt calibrator used for the torqued tension tests of A354 bolts might be greater than that of the steel plates in a bolted joint, thus affecting the relationship between nut rotation and load. If this is the case, the laboratory tests conducted so far do not truly indicate the bolt load to be expected at some given number of turns.

For this reason, several lots of bolts were torqued with a solid material being gripped, and the resulting relationships between elongation and nut rotation were plotted. From these curves, the elongation for a given nut rotation can be measured, and then this elongation, when plotted on a load-deformation curve for the same lot of bolts, will indicate the true bolt load induced by the given nut rotation.

This manipulation is made possible by the assumption that the load-deformation relationship for a given bolt is a property of the bolt itself, and is independent of the bearing material used to resist the applied load. While this assumption is probably not completely true, all indications at this time are that it is very closely approximated for these tests.

The results of this type of test are shown in Fig. 5 for one lot of A354BD bolts torqued, using four-one inch plies of A440 steel in lieu of the bolt calibrator. The heavy line without test points is the load-deformation relationship arrived at from tests in the bolt calibrator. The deformation vs. nut rotation relationships are shown, with the solid test points indicating the relationship for the bolt calibrator, and the open points for the steel plates. It can be seen that there is a marked increase in deformation at a given nut rotation for the steel plates. This is due to the smaller deformation of the plates under load, causing the deformation to be taken up in the bolt itself. At one half turn of nut, an increase in load of 9 kips was indicated for this lot of bolts. Another effect to be noted is the reduced nut rotation until failure for the steel plate, indicating a smaller factor of safety against failure for installation.

Later tests in another study indicated that, if the gripped material were one solid block, the deformation-nut rotation relationship would approach the dashed curve shown in this figure. The deviations from this curve are seen to occur at the initiation of torquing, leading to the belief that these deviations are caused by slack or gaps in the gripped material that close under moderate load.

While these tests indicate a greater load to be expected from ½ turn of nut, it must be cautioned that they were conducted under fairly ideal conditions and that, for an actual joint, the behavior may, in fact, be worse than that shown by the bolt calibrator. These tests do show however, one possible cause of early bolt failures reported in the field when the turn of nut method of installation is used.

2.4 Continuously Torqued Bolts

These tests were conducted to simulate actual field installation methods and the results were compared to the torqued load-deformation relationship obtained using 1/8 turn of nut increments. Several lots of bolts were tested in this manner to either ½ or 3/4 turn of nut. Figure 6 shows the correlation between the two methods. The continuously torqued bolts are indicated by the solid test points superimposed on the load-deformation relationship for incrementally torqued bolts of the same lot. For the four lots tested, the loads achieved by continuous torquing ranged from 90 to 105 percent of those achieved by incrementally torqued bolts, well within the expected variation.

3. CONCLUSIONS

1. No reduction in direct tensile strengths were exhibited in these tests by A354 bolts previously installed by torquing.

2. Repeated installation of an A354 bolt is not advised, for the following reasons: ?

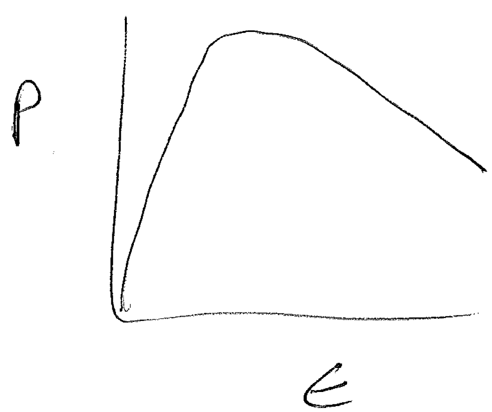
   a) Only a few cycles can be applied before failure.

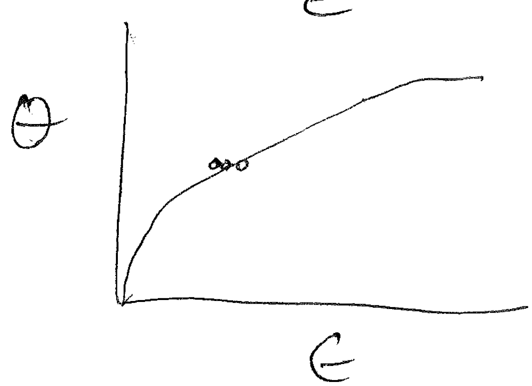
   b) Reduction in clamping force is exhibited after the first installation.

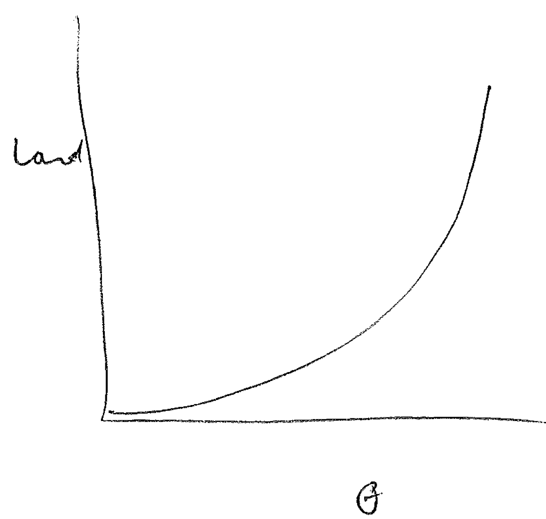
   c) Re-installation immediately becomes difficult and time consuming.

3. For ideal cases, the clamping force of an A354 bolt of a given nut rotation may be higher than indicated by present calibration methods. However, this is accompanied by the disadvantage of a smaller rotation before failure. This effect is also presumed to be present for other types of bolts.

4. The behavior of a continuously torqued A354 bolt is practically identical to that of an incrementally torqued bolt.







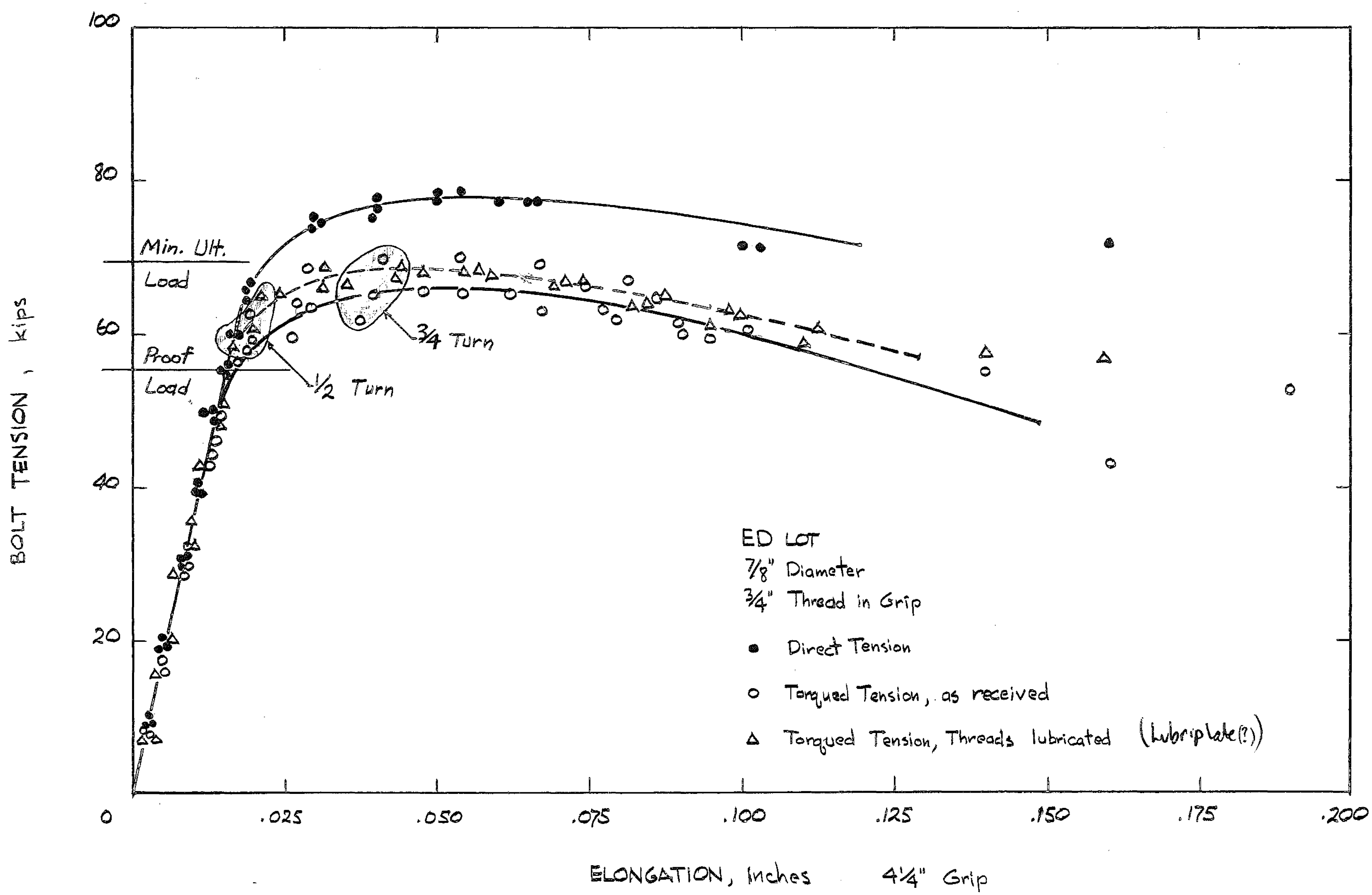


Fig. 1 Typical Tensile Behavior of A354 Bolts A354 BD

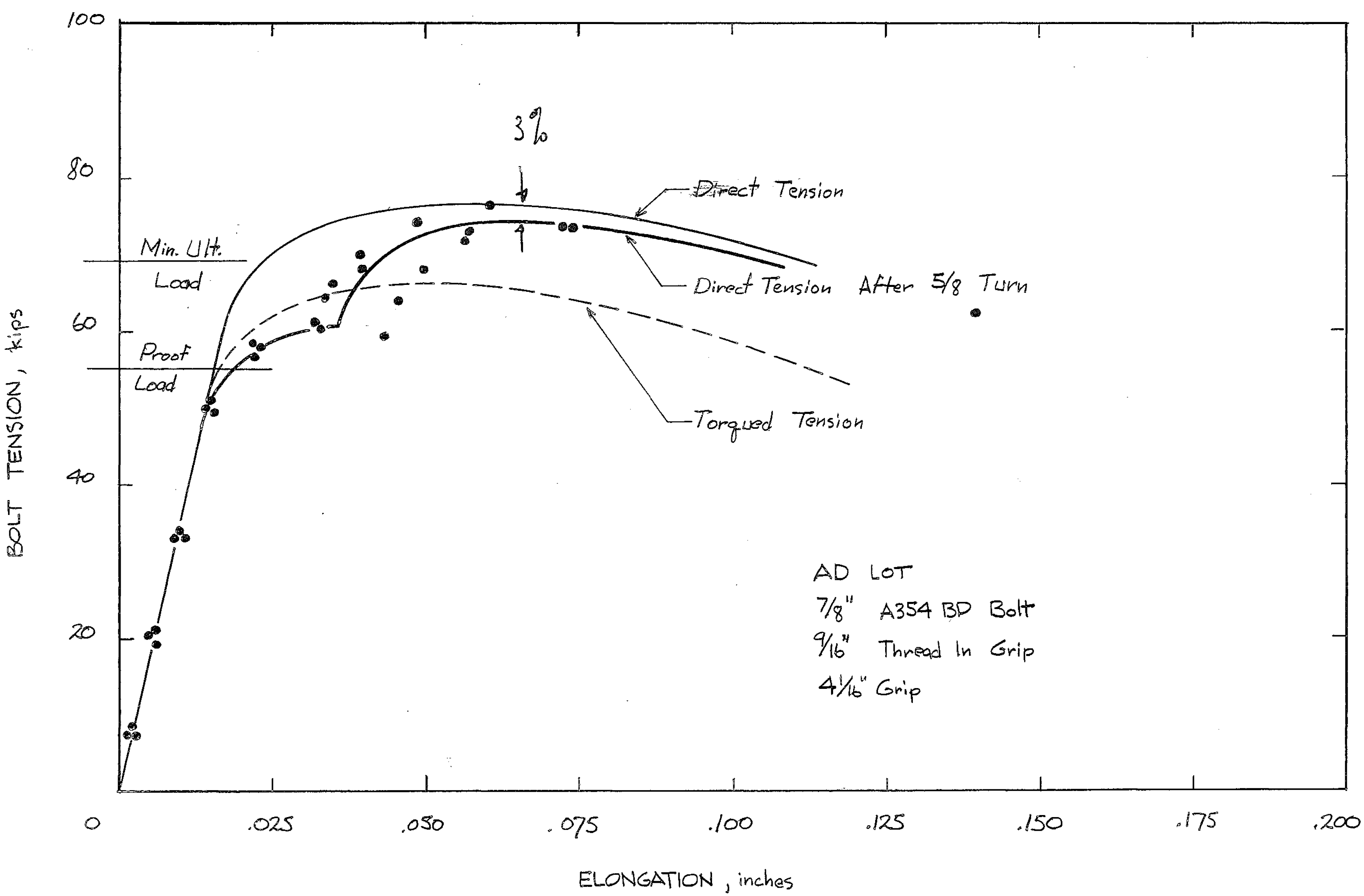


Fig. 2 Reserve Tensile Strength of Torqued Bolts A354 BD

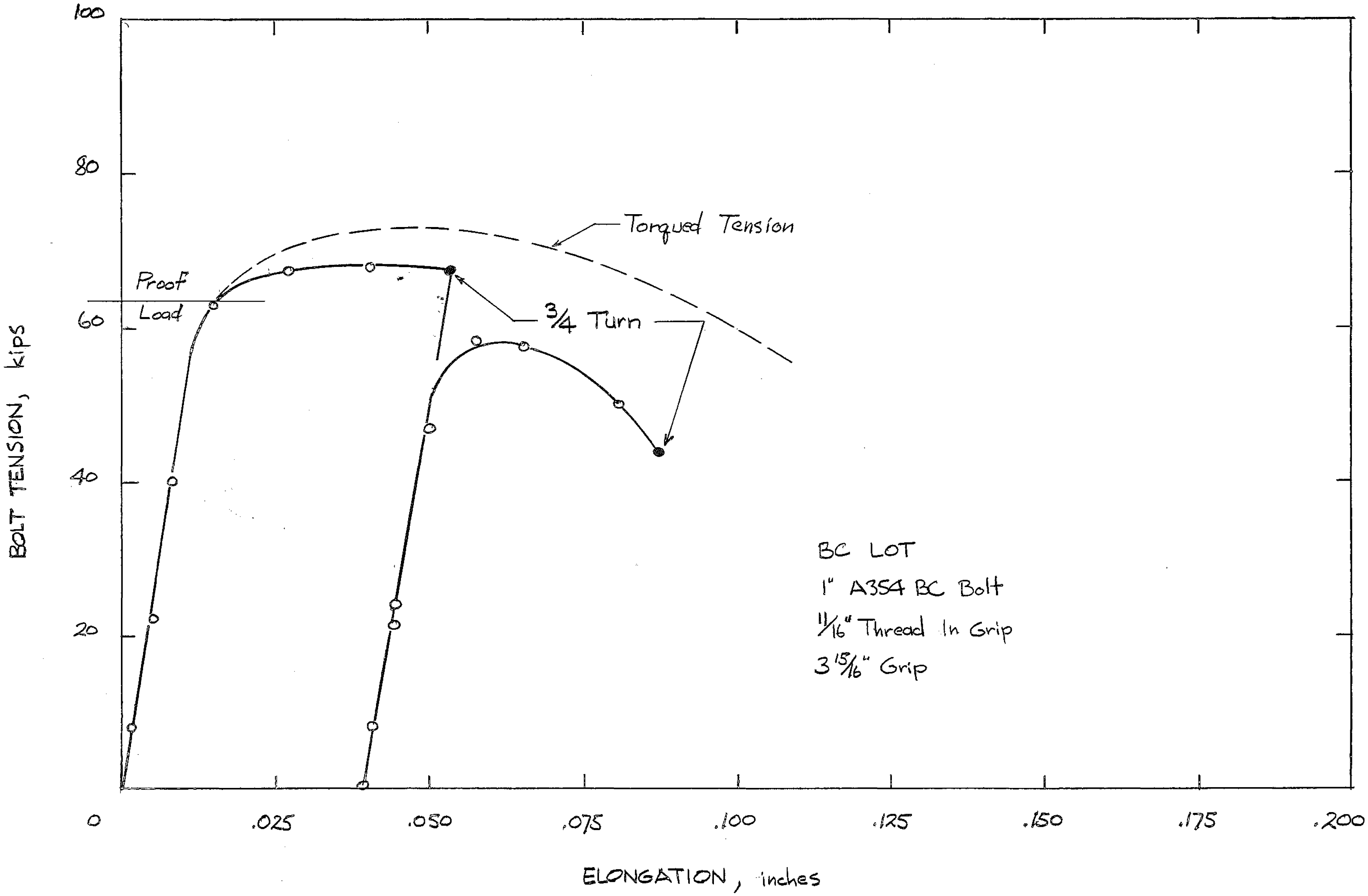
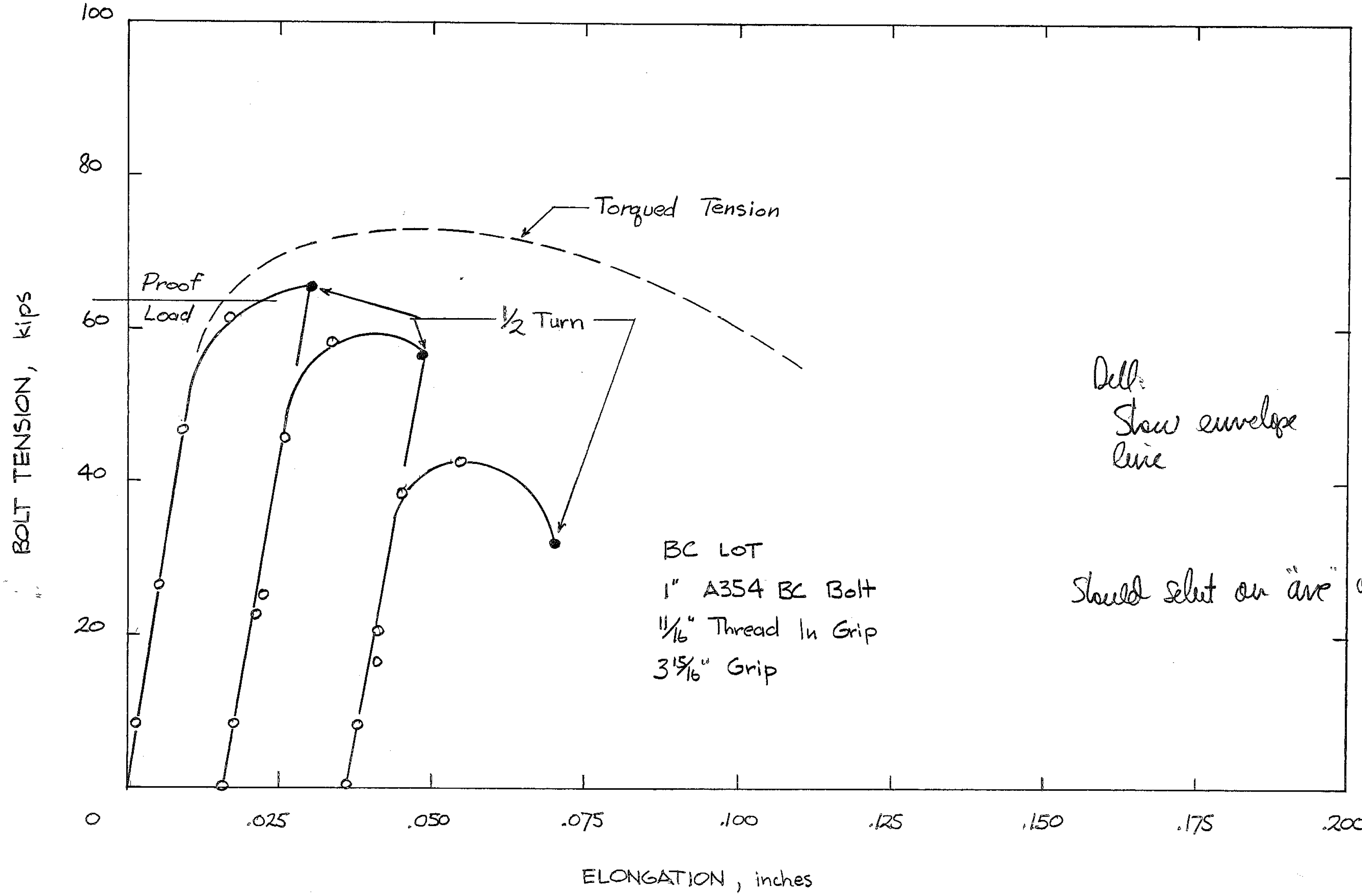


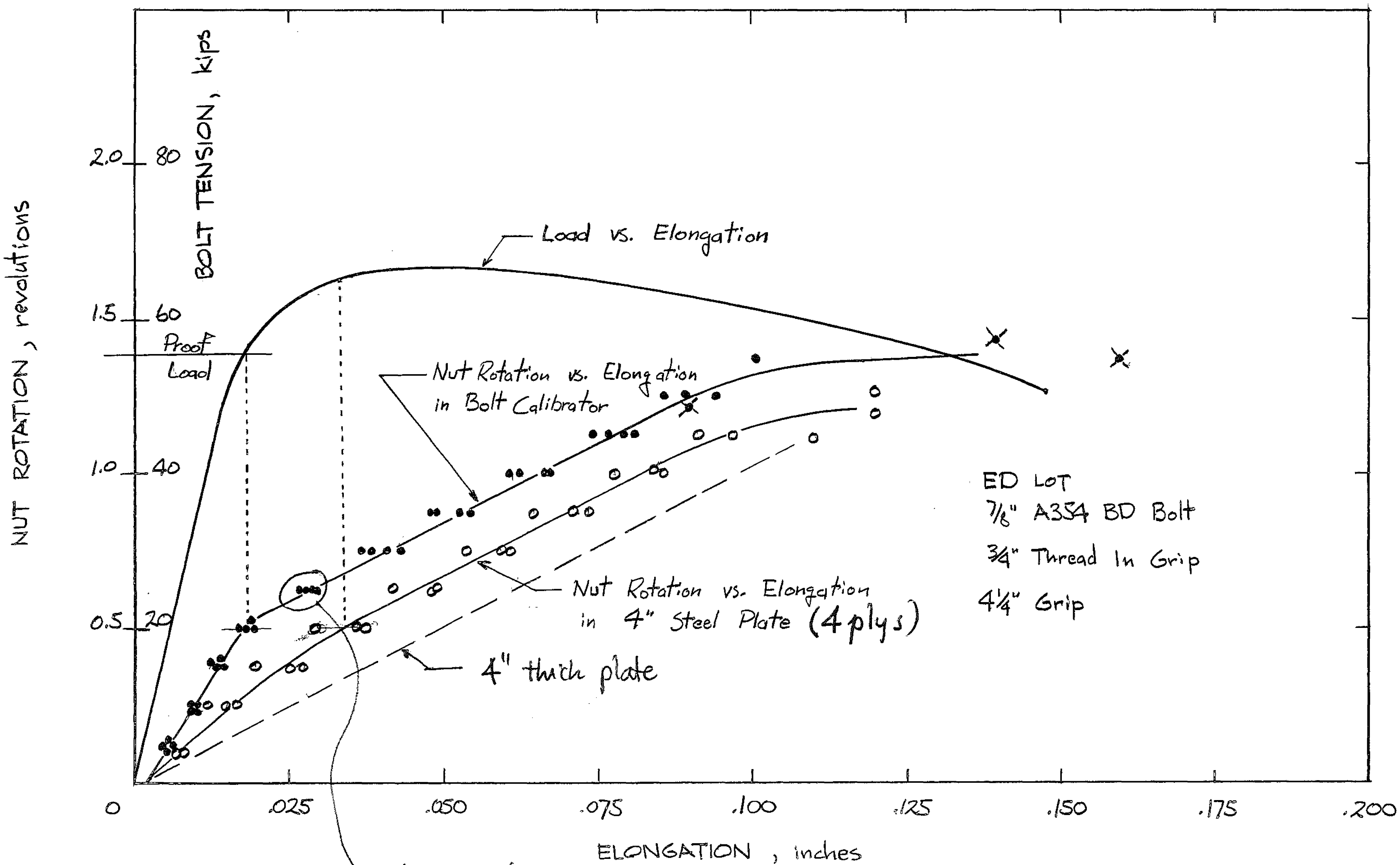
Fig. 3 Reuse of High Strength Bolts



Dell:
Show envelope line

Should select an "ave" or typical

Fig. 4 Reuse of High Strength Bolts



There could be two different points at which

Fig. 5 Bolt Torqued in Solid Plate

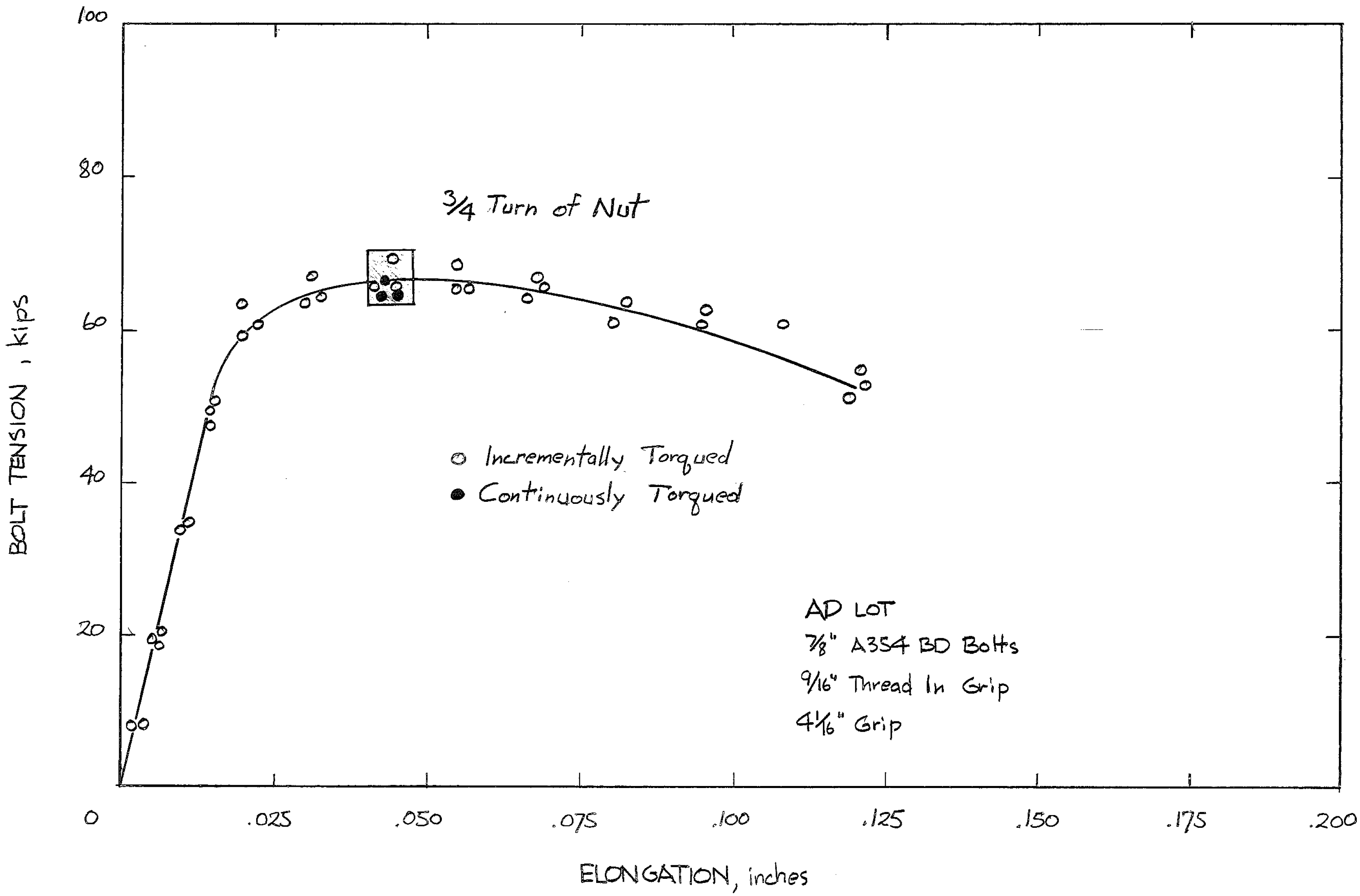


Fig. 6. Comparison of Continuously and Incrementally Torqued Bolts